Development of Parent-Reported Attention/Impulse Regulation and Cognitive Abilities (Intellectual Abilities and Executive Functions) in a Community Sample

Rachael E. Lyon

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Abstract

Parent-reported attention/impulse regulation and cognitive abilities have been used to operationalize and measure the development of self-regulation. Parent-reported attention/impulse regulation is often measured by caregiver ratings. Cognitive abilities, such as intelligence and executive function, are typically assessed using performance-based measures. Both these domains of self-regulation are often implicated in at-risk and clinical samples as important predictors of socio-emotional, academic and vocational outcomes. To better understand the development of competency in these domains, data were examined from a community sample of children and youth, assessed longitudinally across an age range of 8-20 years. Repeated measures ANOVAs, correlations and cross-lagged panel models examined relationships among and between domains over time. Cognitive abilities improved with time, whereas parent-reported attention/impulse regulation remained unchanged across follow-ups. Relationships among cognitive variables and parent-reported attention/impulse regulation were small. We discuss methodological issues that should be addressed in future research assessing the development of these constructs.

Keywords: executive function, cognitive ability, attention, impulse regulation, development, measurement

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Self-regulation (SR) generally refers to the emergence of one's "ongoing, dynamic and adaptive modulation of internal state (emotion, cognition) or behavior" (Nigg, 2017). However, as Nigg (2017) points out, many definitions have been used to define this construct. Indeed, self-regulation likely involves several diverse skills and abilities (e.g., Nigg, 2017; Diamond, 2013). The current study focused on two major ways in which SR has been measured and operationalized: cognitive abilities and parent-reported attention/impulse regulation. The purpose of this study was to examine these two operationalizations through a developmental lens, using a longitudinal design in a community sample. The goal was to determine whether there is developmental change across these domains related to SR and to explore relations among them. Importantly, we do not mean to suggest that cognitive abilities and behaviour ratings are direct indicators of SR. Rather, these measures reflect processes and behaviours thought to underlie SR. We do not make any claims regarding the precision of what these measures are assessing, simply that these are broad indicators often used to assess different domains of SR. While we have chosen to focus more on cognitive types of regulation, other domains (e.g., emotion regulation, perceptual skills, and general processing abilities) may also have important associations among them which are not addressed within the scope of this study. The present study specifically examined two indicators of cognitive ability (i.e., intelligence and executive function tasks) and ratings of attention and hyperactivity/ impulsivity in a community sample of children and youth. Repeated measures analysis of variance was used to estimate developmental change in each of these variables longitudinally across three time points. The temporal emergence of cognitive abilities and parent-reported attention/impulse regulation was also explored using cross-lagged panel analysis models.

Self-Regulation: Cognitive Abilities and Parent Ratings

SR is central to developmental psychopathology, but the general construct is referred to using varying terminology and carries varying meanings across fields and literatures (e.g., personality, social, and cognitive psychology, developmental science, clinical psychology, psychiatry, economics, sociology, neuroscience, and medicine). Depending on the focus (application or explanation), terms such as self-representations, self-concept, and self-monitoring are also used to describe this multifarious construct (Demetriou, 2000). Naturally, investigators have approached SR from diverse perspectives and the extensive range of identified construct domains reflects this. Examples include executive functioning (EF), effortful control, behavioral inhibition, impulse control and impulsivity, risk-taking, cognitive control, among many others (Nigg, 2017). Unsurprisingly, there is no generally accepted theory of SR that delineates the nature and development of these processes adequately. Nevertheless, it is evident that these skills are crucial to children's success across multiple domains, including school, work, home, and interpersonal relationships (de Ridder, Lensvelt-Mulders, Finkenauer, Stok, & Baumeister, 2012; Mischel et al., 2010; Moffitt et al., 2011).

Historically, SR has been assessed through (a) adult ratings of children's behaviour observed in real-world settings such as home or school, and (b) lab-based tasks (e.g., (Kochanska, Coy, & Murray, 2001; Mischel, Shoda, & Rodriguez, 1989). As such, SR can be operationalized in two main ways, parallel to the performance-based vs. rating scale distinction of executive function discussed by Toplak et al. (2013). Though there are likely many separable aspects to measuring SR, this study will focus on two: the first relates to the capacity and efficiency of processing (i.e., cognitive abilities) and the second relates to behavioural tendencies (i.e., parent ratings of attention/impulse regulation). Cognitive abilities and parent-reported attention/impulse regulation indices of SR have been importantly implicated in many different developmental outcomes, predicting family and peer difficulties (Diamantopoulou, Rydell, Thorell, & Bohlin, 2007; Jacobson, Williford, & Pianta, 2011; Mrug et al., 2012), impairments in occupational functioning (Barkley & Fischer, 2011; Mannuzza, Klein, Bessler, Malloy, & Hynes, 1997), and later health and success (Moffitt et al., 2011; Pievsky & McGrath, 2018; Sibley et al., 2014).

Intelligence (IQ) and EF task performance are two types of cognitive abilities frequently associated with the brain's frontal lobes. Despite the strong connections between the conceptualizations of intelligence and EF task constructs, there is some debate regarding the exact nature of their relation (Dennis et al., 2009). The conceptual separation of the two cognitive abilities originates from the paradoxical neuropsychological finding that frontal damage resulting in EF task performance deficits does not produce deficits in performance on intelligence tests (Hebb, 1939; Hebb & Penfield, 1940). Moreover, some investigators argue that traditional intelligence tests differentially relate to EF task performance and do not equally assess the cognitive abilities that likely contribute to general intelligence (Ardila, Pineda, & Rosselli, 2000; Friedman et al., 2006). While many people continue to conceptually separate IQ and EF task performance, there is considerable evidence to suggest that these cognitive abilities capture common variance related to processing efficiency and processing capacity (e.g., Arffa, 2007; Brydges, Reid, Fox, & Anderson, 2012; Stanovich, 2009) and there is also evidence to suggest considerable construct overlap in genetic studies (Engelhardt et al., 2016). Thus, these constructs will be examined separately with the acknowledgement of this overlapping variance.

Executive Function. Executive function tasks assess interrelated abilities that emerge hierarchically in development, although the exact time at which they emerge varies somewhat based on method of study (Miyake et al., 2000). Current definitions of EF describe a set of partially independent top-down functions that support goal-directed behaviour (Banich, 2009; Blair, Raver, & Finegood, 2016; Friedman & Miyake, 2017; Miyake et al., 2000) and complex cognition, including manipulating two things in mind at once, reasoning, temporal projection, and complex mental and action sequences (Barkley, 1997; Diamond, 2013). Some major challenges in research on EF have been methodological, for example, the lack of concordance between performance-based measures and behavioural ratings (Toplak, West, & Stanovich, 2013). The absence of measures that are suitable from early childhood through adulthood, as well as the inconsistency in ability to measure deficits through performance-based neuropsychological assessments has made EF difficult to study. Additionally, there is the conceptual challenge in separating domain-specific functions (e.g., memory, social–emotional, language) from actual EF abilities (Gioia & Isquith, 2004). Despite these challenges, EF is typically assessed using several different performance-based measures. EF was traditionally treated as a unitary construct and measured with single complex “frontal lobe” tasks such as the Wisconsin Card Sorting Test (WCST), however, the past two decades of research best support a model with three correlated but distinct EFs (e.g., Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003; Miyake et al., 2000). Specifically, the tripartite model of EF identifies cognitive flexibility, inhibitory control and working memory as core aspects of EF.

Inhibition or inhibitory control refers to the ability to control attention, thought, and behaviour in the presence of interfering internal or external stimuli, to deliberately inhibit automatic impulses and respond appropriately (Diamond, 2013; Miyake et al., 2000). With increasing inhibitory control, one can better restrict and regulate impulsive behaviours when necessary. A prototypical inhibition task is the Stroop task (Stroop, 1935), in which one needs to inhibit or override the tendency to produce a more dominant or automatic response (i.e., name the color word).

Set shifting (also known as ‘cognitive flexibility’ and ‘attention switching’) describes one’s ability to mentally shift from one task to another, utilizing alternative strategies, and processing more than one source of information (Zelazo, Craik, & Booth, 2004). Set shifting is necessary for multitasking and for processing and managing several sources of information. It is usually measured by tests requiring switching between two timed tasks (Jewsbury, Bowden, & Strauss, 2016). Previous studies have shown conclusively that shifting mental sets incurs a measurable temporal cost (e.g., Jersild, 1927; Rogers & Monsell, 1995), particularly when the shifting must be driven internally, rather than by external cues (Spector & Biederman, 1976). As such, set shifting is usually measured using a ‘differential’ paradigm; that is, using tasks that have a component that requires no shifting between mental sets and one that does. The Trail Making Test (Reitan, 1955, 1958) Part B minus Part A is frequently used as a measure of set shifting (Arbuthnott & Frank, 2000).

A third core EF process identified in the Miyake (2000) model is *working memory*, or rather the updating and monitoring of working memory representations, which involves replacing old information with new information relevant to the task at hand (Jewsbury et al., 2016). Importantly, the updating process requires the dynamic manipulation, rather than passive storage, of information in the multicomponent system of working memory (Miyake et al., 2000) and is used to achieve goals and meet task demands (Baddeley, 2000; Baddeley & Hitch, 1994; Engle, Tuholski, Laughlin, & Conway, 1999). Updating is often measured by a complex task like the N-back task, where individuals must constantly monitor and update number or visual-spatial information in working memory (Miyake et al., 2000).

Intelligence. Intelligence, or intellectual ability, involves various mental abilities such as reasoning, planning, problem-solving, and abstract thinking (Gottfredson, 1997). General intelligence, or Spearman's g, refers to the existence of a broad mental capacity that influences performance on cognitive ability measures (Spearman, 1904), and is usually assessed using tests like the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999). Over the 100 years since Spearman's (1904) original work, factor analyses have continued to be applied to correlation and covariance matrices from cognitive test batteries. Contemporary, hierarchical representation of cognitive ability structure which consist of specific factors nested within general factors draw largely from Cattell's (1963; 1971) seminal work on the distinction between fluid and crystalized cognitive abilities which govern performance on nonverbal and verbal cognitive tasks, respectively. More specifically, fluid general ability (Gf) represents complex mental abilities needed for reasoning and abstract thinking and reflects the capacity to apply one's skills and knowledge in novel situations and unfamiliar tasks (Cattell, 1963, 1971). Crystalized general ability (Gc), on the other hand, represents the set of skills and knowledge obtained through experience, and is primarily a store of verbal or language-based declarative ("what") and procedural ("how") knowledge (McGrew, 2009). While intelligence is not conventionally described as a measure of self-regulation, because intelligence is often significantly associated with EF task performance capacity (Arffa, 2007; Brydges et al., 2012; Stanovich, 2009) and a significant covariate in EF task performance (Dennis et al., 2009), it was included as an additional index of cognitive abilities examined in this study.

Parent-reported attention/impulse regulation. The emergence of general self-regulation skills has frequently been indexed by parent ratings of behaviour. For example, parent ratings of child temperament revealed a higher order factor comprising focusing and shifting of attention, inhibitory control, perceptual sensitivity, and low threshold for effortful control (Rothbart, Ahadi, Hershey, & Fisher, 2001). Parent ratings of attention/impulse regulation include items relating to the observed cognitive, motor, and impulse control of the child, and are completed by the primary caregiver. These scales are continuous in nature and involve rating the degree to which a child has difficulties with a given behavior. For example, the assessment of inattention, hyperactivity and impulsivity are conventionally used to assess children who have difficulties related to Attention Deficit/Hyperactivity Disorder (ADHD).

ADHD is a neurodevelopmental condition, with developmental onset and course, which is characterized by behavioural symptoms of inattention, impulsivity and hyperactivity, or both that are inconsistent with developmental level and causes functional impairment across multiple settings (American Psychiatric Association, 2013). Classic models of ADHD indicate that these behavioural symptoms can be explained by underlying deficits related to self-regulation (Barkley, 1997). One of the more recently developed parent-report measures of symptoms associated with ADHD is the Strengths and Weaknesses of ADHD Symptoms and Normal Behavior rating scale (SWAN; Swanson et al., 2012). The SWAN differs from most other scales in how the questions are phrased. Rather than focusing on deficits, it asks parents to rate their child relative to normal behavior expectations of same aged peers (e.g., Compared to other children, how well does this child . . . Sustain attention on tasks or play activities?). Parents respond using a 7-point Likert-type scale. Uniquely, the SWAN scale assesses behaviour on a continuum which is particularly useful for non-clinical populations and research aimed at understanding strengths as well as weaknesses in attention and impulse control.

The psychometric properties of the SWAN support its use in both identifying those children at risk for ADHD, as well as measure additional variance at the adaptive end of the ADHD symptom dimensions (Arnett et al., 2013). Previous research has examined the psychometric properties of the SWAN, as well as the reliability and validity of translated versions (Arnett et al., 2013; Hay, Bennett, Levy, Sergeant, & Swanson, 2007; Lakes, Swanson, & Riggs, 2012; Polderman et al., 2007; Young, Levy, Martin, & Hay, 2009). Although the authors acknowledge developmental changes in ADHD symptoms, these age-related changes on the SWAN-ratings have been minimally explored. Hay and collaborators (2007) reported on the developmental effects of the SWAN in their study investigating differences between it and another ADHD scale. Two different-aged samples of Australian twins were included: the younger sample ranged from 6 to 9 years (N= 707, mean age = 7.6 years, SD = .91) and the older sample ranged in age from 12 to 20 years (N= 887, mean age = 15.2 years, SD = 2.54). The SWAN scale was coded such that a high score indicates a higher level of ADHD symptoms or problem behaviors (-3= far above average; -2 = above average; -1=somewhat above average; 0 = average; 1 = somewhat below average; 2 = below average; 3 = far below average). Investigators noted that in this non-clinical sample, younger children scored higher (i.e., had more parent-reported problems) than the older children on the SWAN for both inattention and hyperactivity-impulsivity subscales (Hay et al., 2007).

In addition to developmental differences, the correlates of attention/impulse regulation skills are not well understood in developmental samples. One of the prevalent theories in the ADHD literature is that performance on neuropsychological measures of intelligence and executive function task performance are importantly related to the successful development of attentional and impulse regulation skills (Diamond, 2013; Frazier, Demaree, & Youngstrom, 2004; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). For example, Halperin et al (2008) found that when comparing adolescents without ADHD to adolescents who had received a diagnosis of ADHD during childhood, only individuals whose ADHD symptoms persisted (i.e., continue to meet diagnostic criteria for ADHD) differed from controls on executive function tasks. Adolescents whose ADHD had remitted did not perform significantly different from healthy controls, suggesting that neuropsychological development may be importantly related to the successful development of attentional and impulse regulation skills (Halperin, Trampush, Miller, Marks, & Newcorn, 2008).

Development of cognitive abilities and parent-reported attention/impulse regulation.

Most models and taxonomies of SR highlight the developmental course of cognitive abilities and parent-reported attention/impulse regulation (e.g., Nigg, 2017; Diamond, 2013). EF develops rapidly in the preschool years, and adult-level performance is achieved during late adolescence (Anderson, 2002; Steinberg, 2005; Zelazo et al., 2003). As compared to other cognitive abilities, the developmental trajectory for maturation of EF tasks is relatively protracted. This is commonly attributed to the necessity of prefrontal cortex (PFC) engagement, particularly of the dorsolateral region, to perform these high-level cognitive processes which is not considered to be fully developed until early adulthood (Bunge & Zelazo, 2006; Diamond, 2002; Durston et al., 2006; Moriguchi & Hiraki, 2009). Although children have been shown to activate the PFC when completing EF tasks, they show a more diffuse network of activation as compared to adults, which supports the notion that this network gains efficiency over the course of development (Casey, Giedd, & Thomas, 2000). Inhibitory control of attention (interference control at the level of perception) is challenging for young children. Although preschool-aged children can successfully complete lab-based inhibition tasks, both speed and accuracy of inhibitory control continues to mature into adolescence (Diamond, 2013). Cognitive flexibility is the last of the three core EF to emerge (around 7 to 9 years of age), and is thought to build on the other two (Diamond, 2013).

In non-clinical populations, fluid and crystallized intelligence are highly associated in young children and differentiate with age (Li et al., 2004; Tucker-Drob, 2009). Even when these two abilities differentiate, they are still related to a certain extent. That is, these two aspects of intellectual ability have slightly different trajectories across development even though they are highly related and representative of general intelligence (Deary, Penke, & Johnson, 2010). Gf improves through childhood and peaks in adolescence while Gc continues to develop until early adulthood (Cattell, 1963). For this reason, Gf and Gc were examined separately. However, as Gf and Gc are highly related with each other and representative of general intelligence, performance on their respective indices utilized in this study were expected to be positively correlated.

Much of what we know about attention/impulse regulation across development comes from studies of children with ADHD (conceptually the psychopathology most closely related to attention/impulse regulation problems). In individuals with ADHD, the symptom profile changes over the lifespan, with a notable reduction in the number of symptoms (particularly hyperactivity) for many individuals in adolescence (Murray, Robinson, & Tripp, 2017; Sasser, Kalvin, & Bierman, 2016). In general, it is reported that symptoms tend to decrease from childhood to young adulthood regardless of ADHD severity, although the developmental course appears to be more stable for symptoms of inattention and total symptoms in highly impaired individuals (Döpfner et al., 2015; Todd et al., 2008). Despite changes in presentation, studies have shown that as many as 70% of children with a childhood diagnosis of ADHD continue to meet full ADHD diagnostic criteria in adolescence (Langley et al., 2010). It is evident that a substantial proportion of children have impairing attentional problems that persist into young adulthood. The trajectory of ADHD symptoms in a general-population sample similarly demonstrates decreasing hyperactivity with age, and relative stability of inattention symptoms from early childhood through late adolescence (Holbrook et al., 2016). The development of these indicators of self-regulation remain a critical question, with respect to relative changes and/or constancy across both community and clinical samples.

Associations among cognitive abilities and parent-reported attention/impulse regulation.

Similarly, much of the evidence for a link between attention/impulse regulation problems and cognitive abilities comes from clinical studies of individuals diagnosed with ADHD. Aspects of EF, such as inhibition, working memory, and set shifting have been shown to correlate with ADHD behaviours (i.e., inattention, hyperactivity and impulsivity) in that poorer EF performance is associated with greater ADHD behaviours (Adler et al., 2017; Faraone et al., 2015; Fried et al., 2016; McLuckie et al., 2018; Willcutt et al., 2005). Some researchers contend that EF deficits are not actually part of the core etiology of ADHD, but rather develop because of comorbidities or are only present in a small subset of individuals (Marchetta, Hurks, Krabbendam, & Jolles, 2008; Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005; Willcutt et al., 2005). Nevertheless, EF deficits are consistently found to be prevalent among individuals with ADHD (Adler et al., 2017; Barkley, 1997; Frick, Bohlin, Hedqvist, & Brocki, 2018; Silverstein et al., 2018), and deficits in EF have been found as early as 3 to 5 years of age (Seidman, 2006). By and large, structural and brain imaging research also supports a relationship between ADHD and EF deficits. Findings suggest that specific areas of the brain (e.g., frontostriatal and frontoparietal networks) that are highly related to executive function processes are underactive in those with ADHD (Faraone et al., 2015), as well as delays in cortical maturation (Makris et al., 2007; Shaw et al., 2007; Shaw et al., 2011) and decreased volume of these regions (Nigg, 2009). Like the behavioural research, however, findings from neuroimaging and neurocognitive studies that focus on the precise neuropsychological deficits and brain regions involved in ADHD are also inconsistent. The magnitude, direction, localization, laterality, and clinical significance of the functional and structural abnormalities differ from study to study (Hoogman et al., 2017; Rosch et al., 2018; Silk et al., 2016).

The discordant findings regarding EF tasks and ADHD in the literature may be attributable to numerous things. An important limitation is the use of the different definitions and (sometimes inadequate) methods of assessing EF (Barkley & Murphy, 2010; Biederman et al., 2006). Furthermore, children with ADHD are a heterogeneous population and individual differences in behavioural symptoms and neurocognitive function are extremely variable across and within samples (Biederman et al., 2009; Himelstein, Newcorn, & Halperin, 2000). Nevertheless, the literature suggests that cognitive abilities (such as EF tasks) are, at least in part, related to the etiology of self-regulatory behaviours like inattention and hyperactivity-impulsivity.

The few studies that have examined attention/impulse regulation in unselected, community samples have found similar results (e.g., Friedman et al., 2007; Kuntsi, Andreou, Ma, Börger, & van der Meere, 2005; Thorell & Wåhlstedt, 2006), suggesting that the relation between attention/impulse regulation problems and EFs is not exclusive to clinical populations. For example, Thorell and Wåhlstedt (2006) found that EF was associated with symptoms of ADHD, with medium effects sizes, in a community-based sample of preschool-aged children.

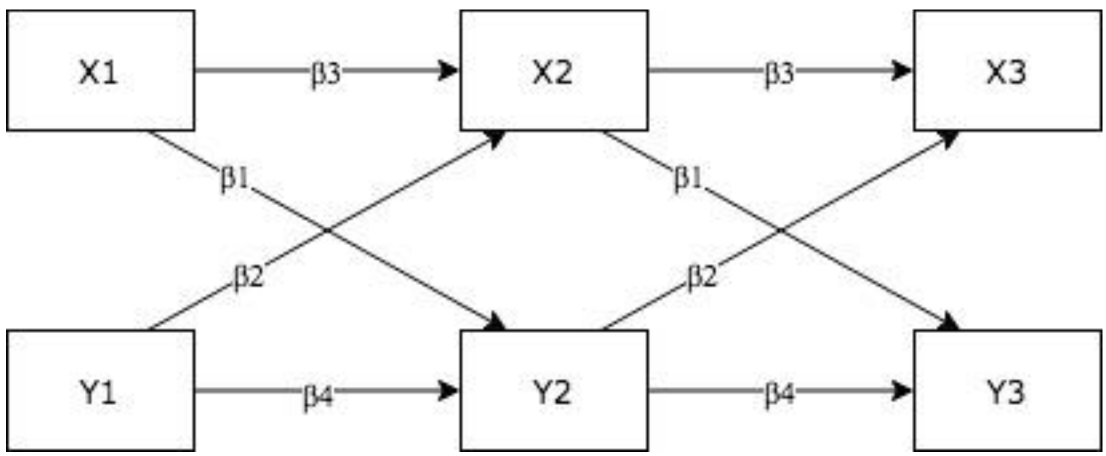
Friedman et al (2007) demonstrated that attention problems significantly and differentially relate to all three EFs in a general-population sample, particularly with inhibiting ability measured using performance-based tasks (e.g., Stroop, Stop-Signal Task). Results suggested stable relationships between attention problems across time to later EFs and IQ, and that initial levels of attention problems, rather than changes across time, predict later executive control (Friedman et al., 2007).

Limited research has been done to date examining the relationships between the trajectories of EF and attention/impulse regulation, and those that have done so have focused on clinical populations. Rajendran et al. (2013) examined changes in neuropsychological functioning with the trajectory of ADHD-related symptoms and impairment in children identified as “high-risk” for developing ADHD. Data were collected annually between preschool and school-age. Neuropsychological functioning (i.e., EF performance) at baseline was not significantly associated with the magnitude of change in ADHD severity, however, individuals with greater neuropsychological growth over time had a greater diminution of ADHD severity and impairment (Rajendran et al., 2013).

Current directions

To date, the majority of research on the association between attention/impulse regulation and performance on cognitive tasks comes from the clinical populations (e.g., ADHD). The literature presented so far shows a lack of consensus regarding the emergence, developmental trajectory and relationships among IQ, EF tasks and parent-reported attention/impulse regulation in both community and clinical populations. Thus, in this study, the stability and relationships between these variables was examined over time to better understand how these operationalizations of self-regulation influence each other over time in a community sample using cross-lagged panel models. Causal predominance can be examined by comparing standardized coefficients of the cross-lagged paths (Kearney, 2017). An example of a three-wave, or three time-point, cross-lagged panel model is presented in Figure 1. In the depicted model, paths are constrained to equality across time. Thus, β1 represents the cross-lagged effects from X1 on Y2 and from X2 on Y3.

Figure 1. Example of a Three-Wave Cross-Lagged Panel Model



Summary of the Current Study

This study had three goals. First, mean differences of cognitive variables and parent-reported attention/impulse regulation were compared at each time point. It was expected that performance on cognitive variables and parent-reported behaviour would improve across time points, consistent with the research showing an increase in cognitive abilities, and a decrease in attention/ impulse regulation problems over development. Second, bivariate correlations between parent-reported attention/impulse regulation and performance on cognitive ability measures were examined, where larger correlations were expected between SWAN scores and WASI vocabulary, WASI matrix reasoning, TMT, and Stroop scores at earlier time points as compared to later time points. The final goal was to examine the directional nature of the relationship between cognitive abilities and parent-reported attention/ impulse regulation over time.

Method

Participants

The current study used data from a sample which consisted of children recruited from suburban and rural schools as part of a longitudinal research project. Data from this study are previously reported (Toplak, West, & Stanovich, 2014). At time one (T1), 204 children were included for analysis (110 males) ranging from 8 to 14 years (M = 10.15, SD = 1.7). Follow-up data were collected twice at three-year intervals. Time two (T2) includes data from 165 children (86 males), ranging from 10 to 18 years (M = 13.23, SD = 1.8) and time three (T3), 134 children (77 males) from 13 to 20 years (M = 15.97, SD = 1.8). This sample would be characterized as high functioning (T1 FSIQ M = 108.19, SD = 13.0) with relatively high socioeconomic status. At T2, parents were asked to report on their educational attainment. Of the 156 mothers for whom data were available, 48 (23.5%) had professional degrees, 83 (40.7%) completed college or university, 3 (1.5%) had some college or university, 15 (7.4%) completed high school, 1 (0.5%) completed less than high school and 4 participants did not report on their educational status. Of the fathers, 42 (20.6%) had professional degrees, 67 (32.8%) completed college or university, 14 (6.9%) had some college or university, 22 (10.8%) completed high school, 3 (1.5%) completed less than high school and 8 participants did not report on their educational status.

Measures

Parent-reported attention/impulse regulation. The SWAN rating scale (Swanson et al., 2012) was used to measure parent ratings of attention impulse regulation. This scale is based on observations of normal and abnormal distributions of ADHD-typical behaviours. As such, the SWAN scale uses a strength-based formulation to assess behaviour on a continuum whereby higher scores indicate better self-control (i.e., better controlled attention and behaviour). Parents were asked to rate their child's behaviour relative to same age peers for each of the 18 items using a seven-point scale ranging from *far below average* to *far above average* (1= far below average; 2 = below average; 3 = somewhat below average; 4 = average; 5 = somewhat above average; 6 = above average; 7 = far above average). Thus, total scores could range from 18- 126. Data were available from 191 parent reports at T1, 156 parent reports at T2 and 134 parent reports at T3. Domain scores (inattention, hyperactivity and impulsivity) as well as a total SWAN composite score were used to describe attention/impulse regulation. The SWAN demonstrates comparable validity and reliability to common parent report measures of ADHD, has skewness and kurtosis statistics within the range expected for a normal distribution, and is able to measure positive attention and impulse regulation behavior thus capturing more variance at the adaptive end of ADHD symptoms (Arnett et al., 2013; Hay et al., 2007; Lakes et al., 2012; Polderman et al., 2007; James M. Swanson et al., 2012).

Cognitive Ability Measures

Verbal and Nonverbal Intelligence. The Vocabulary and Matrix Reasoning subtests from the Wechsler Abbreviated Scales of Intelligence (WASI; Wechsler, 1999) were used as indices of verbal and nonverbal ability. In the vocabulary subtest, participants are given words and asked their meaning whereas in the matrix reasoning subtest, participants are shown visual matrices with something missing and asked to select the response option that completes the matrix or series. These measures are reported to have high reliability and validity (Sattler, 2008). Raw non-age corrected scores were used for these tasks. Cognitive abilities have been shown to be more dependent on age in children than in young adults, as well as more highly associated with ratings of cognitive and behavioural regulation (Rizeq, Flora, & Toplak, 2017). These authors concluded that variables highly associated with age (such as EF and verbal and nonverbal ability) should not be age-corrected when assessing associations among cognitive constructs, especially during periods when there is rapid change in cognitive abilities, such as during childhood and adolescence. Participants could attain a maximum total score of 68 on the vocabulary subtest and a maximum total score of 31 on the matrix reasoning subtest. A higher score indicated higher intellectual ability.

Executive Function (Inhibition). The Stroop Task was used to measure inhibition. In this task, participants had to name the incongruent font colour of colour words and resist the tendency to read colour words. There were three different conditions, each with 24 items arranged in a 4 x 6 matrix: a colour-naming condition, a word naming condition, and an interference condition in which participants were asked to name the colour of the font in which the colour word was printed. The inhibition score of the Stroop task was calculated by subtracting the total naming time (in seconds) for the color condition from the total naming time for interference condition. Lower scores indicate better inhibition skills.

Executive Function (Set-Shifting). The Trailmaking Test (TMT; Reitan, 1955, 1958) was used to measure set-shifting. Both parts of the test were administered. Each includes 25 circles distributed on a sheet of paper. Part A asks participants to connect 25 numbered circles in ascending order. Part B asks participants to connect 12 lettered and 13 numbered circles, whereby the participant is instructed to alternate between numeric and alphabetic order, going from 1 to A to 2 to B to 3 to C, and so on. Total completion time in seconds is recorded with higher time for completion indicating lower set-shifting ability. To remove the effects of individual differences in processing speed, the set-shifting score was obtained by removing the time taken to complete Part A from Part B. Scores were then reflected so that higher scores are indicative of better set shifting.

Procedure

Assessments were administered by trained graduate students and bachelor's-level research assistants under the supervision of a licensed clinical psychologist. Measures used in this study were part of a larger set of questionnaires and tests administered at each time point. Parent consent and child assent were obtained before starting the study. The administration of task order was as follows: demographics form, WASI Vocabulary, WASI Matrices, Stroop, and TMT. One parent completed the SWAN questionnaire for each child.

Data Analysis

The present analyses used two executive function tasks and two intelligences indices, as well as parent-reported attention/impulse regulation. There were 13 missing parents' rating of inattention and impulse regulation at baseline (T1). There were no missing data at the following time points. At both follow-ups, sample retention was good (T2: $n = 156$, 76% of the total sample; T3: $n = 135$, 66% of the total sample). At T2, participants who continued in the study displayed higher intelligence than participants who dropped out, $t\,(202) = 2.32$, $p = .02$. At T3, retention was not significantly related to intelligence, $t\,(154) = 0.37$, $p = .71$.

Before testing the hypotheses, the data were visually screened and descriptive statics were run, including indices of normality. To address the first goal of developmental changes, repeated measure univariate analyses of variances (ANOVA) were conducted for cognitive variables and parent-reported attention and impulse regulation[1]. For each repeated measures ANOVA, Mauchley's test of sphericity was conducted to assess the null hypothesis that the variance-covariance matrix is spherical in the population, against the null that it is not. Where the assumption of sphericity has not been met, the *F*-test is reported with the Huynh-Feldt correction. Post-hoc pairwise comparisons were performed using the Sidak correction for multiple comparisons at an alpha level of .05. To address our second goal, bivariate product-moment correlations were used to measure the linear associations among the measures of intelligence, EF, and ratings of inattention and impulse regulation. The third goal was addressed using cross-lagged panel analysis to test the directional associations between variables over time. Models were estimated using R software with the lavaan package (version 0.5-17; Rosseel, 2012). Overall model fit was assessed using the standardized root mean square residual (SRMR) and robust versions of the root mean square error of approximation (RMSEA), comparative fit index (CFI), and Tucker-Lewis index (TLI) advocated by Brosseau-Liard and Savalei (2014; Brosseau-Liard, Savalei, & Li, 2012); for RMSEA and SRMR, values $< .08$ are typically considered indicative of adequate model fit, whereas values of CFI and TLI $> .90$ indicate acceptable model fit.

Specifically, a cross-lagged panel was implemented to assess the temporal relationships between parent-reported attention/impulse regulation and cognitive abilities (verbal ability, non-verbal ability, set-shifting and inhibition) at baseline (T1), 3-years (T2) and 6- years (T3) post-baseline. Cross-lagged panel analysis was chosen because it allows for multiple relationships and

[1] We also examined developmental change using growth curve modelling. To accomplish this, data were restructured by age rather than time point. Results did not suggest a different developmental pattern, as such, these analyses are described in the appendix.

their directionality to be analyzed simultaneously. The relative strengths of longitudinal relationships were determined through comparison of standardized betas.

Results

Descriptive Statistics

The data were visually screened and the univariate distributions of all items were inspected as well as scatterplots of the bivariate distributions. Descriptive statistics are presented in Table 1 on each of the raw variable scores. At T1, parents reported their children to have well developed attention and behaviour regulation (SWAN composite M = 85.74, SD = 17.0), where the potential range is from 18 to 126. The 13 children with missing parent reports of SWAN ratings in the child sample were compared to the rest of the sample on the four cognitive measures, with no notable differences. All variables' means for these 13 children were within the one standard error of the mean of the full sample of children with no missing data.

Table 1

Descriptive Statistics of Variables at Each Time Point

Variables	***n***	**Mean**	**Median**	**SD**	**Range (min, max)**	**Skew**	**Kurtosis**
			Time 1				
Age	204	10.15	10.00	1.73	8, 14	0.58	-0.61
WASI Vocabulary	204	41.22	42.00	7.65	21, 61	0.07	-0.40
WASI Matrix Reasoning	204	22.88	24.00	5.16	6, 32	-1.16	1.24
Stroop Interference	204	36.69	34.50	14.03	9.0, 83.0	0.78	0.75
TMTb-a	204	69.02	58.90	44.33	-2.0, 256.1	1.54	3.26
SWAN Inattention	191	42.21	41.00	9.26	15, 60	-0.15	-0.38
SWAN Hyperactivity	191	28.97	28.00	6.14	10, 42	0.13	-0.52
SWAN Impulsivity	191	14.55	14.00	3.13	4, 21	0.03	-0.20
SWAN Composite	191	85.74	83.00	17.03	29, 121	-0.02	-0.25

			Time 2				
Age	156	13.23	13.00	1.84	10, 18	0.63	-0.34
WASI Vocabulary	156	53.10	54.00	7.25	32, 72	-.023	0.22
WASI Matrix Reasoning	156	27.40	28.00	3.17	15, 33	-1.08	2.36
Stroop Interference	156	23.07	22.14	8.48	5.2, 47.0	0.47	0.14
TMTb-a	156	38.80	36.80	21.42	-38.0, 99.0	0.21	1.34
SWAN Inattention	156	43.06	43.50	9.34	18, 63	-0.03	-0.50
SWAN Hyperactivity	156	29.76	29.00	6.29	12, 42	0.11	-0.55
SWAN Impulsivity	156	15.01	15.00	2.91	9, 21	0.14	-0.76
SWAN Composite	156	87.83	86.50	17.14	44, 124	0.09	-0.52
			Time 3				
Age	134	15.97	16.00	1.79	13, 20	0.53	-0.52
WASI Vocabulary	134	52.37	52.00	6.82	36, 67	-0.13	-0.36
WASI Matrix Reasoning	134	27.82	28.00	3.55	10, 35	-1.39	4.61
Stroop Interference	134	17.64	17.31	6.02	2.5, 34.0	0.24	-0.03
TMTb-a	134	37.05	32.30	19.63	-0.4, 102.0	1.40	2.31
SWAN Inattention	134	43.13	44.00	9.83	13, 61	-0.26	-0.37
SWAN Hyperactivity	134	29.91	30.00	6.33	15, 42	-0.03	-0.93
SWAN Impulsivity	134	15.05	15.00	3.21	6, 21	0.04	-0.74
SWAN Composite	134	88.10	88.50	17.69	35, 124	-0.08	-0.54

Note. WASI Wechsler Abbreviated Scale of Intelligence; *TMTb-a* Trailmaking Test Part B minus Part A; *SWAN* Strengths and Weaknesses of ADHD-symptoms and Normal-behaviors

Repeated Measures Analysis of Variance

We used repeated measure univariate analyses of variances (ANOVA) to examine developmental change in cognitive variables and parent-reported attention and impulse regulation, which are presented in Table 2. A significant *F* value indicates that scores differ significantly between at least two time points, and can be further explored to determine where significant differences lie. Partial eta squared ($\eta 2$) represents the approximate amount of variation in score for which the level of the independent variable (time) can explain.

Table 2

Repeated Measure ANOVA results

Variables	***n***	***F***	***p***	*η2*	*M* (*SD*) T1	*M* (*SD*) T2	*M* (*SD*) T3
WASI Vocabulary	134	275.66	< .001	.675	41.96 (7.4)	53.48 (7.2)	52.37 (6.8)
WASI Matrix	134	112.91^	< .001	.457	23.26 (4.8)	27.28 (3.0)	27.82 (3.5)
Stroop Interference	134	197.33^	< .001	.597	37.10 (14.7)	23.64 (8.3)	17.64 (6.0)
TMTb-a	134	62.22^	< .001	.313	65.17 (41.9)	37.67 (20.6)	37.05 (19.6)
SWAN Inattention	131	0.91	.403	.007	42.24 (8.7)	43.14 (9.5)	42.92 (9.8)
SWAN Hyperactivity	131	3.60	.029	.027	28.71 (5.9)	29.86 (6.2)	29.83 (6.3)
SWAN Impulsivity	131	2.25	.108	.017	14.49 (3.0)	14.95 (2.8)	14.98 (3.2)
SWAN Composite	131	2.54	.081	.019	85.44 (16.1)	87.95 (17.2)	87.73 (17.6)

Note. ^ denotes F-tests which are reported with the Huynh-Feldt correction

Cognitive Abilities. Significant differences between scores were detected for all cognitive ability indices. Mean WASI vocabulary raw scores are significantly different from each other at T1 and T2, and T1 and T3, such that the mean at T1 is significantly lower than T2 and T 3. Mean scores at T 2 and T3 do not differ significantly from each other. This result suggests vocabulary raw scores improve at 3 year follow up and increased score remains stable at 6 year follow up. Results indicate WASI matrix reasoning follows an identical pattern to WASI vocabulary.

Mean Stroop interference scores at all time points are significantly different from each other, such that the mean of Stroop scores at T1 is significantly higher than T2, which is significantly higher than T3. As would be expected, Stroop Interference performance improves at each follow up, suggesting better interference control with development. On the other hand, TMT b minus a score at T1 is significantly higher than T2 and T3 but mean scores at T2 and T3 do not differ significantly from each other. This result suggests TMT b minus a scores improve at 3 year follow up and improvement remains stable at 6 year follow up.

Parent-reported attention/impulse regulation. There is not a significant difference between mean SWAN composite, inattention or impulsivity scores between any of the time points. Regarding the hyperactivity subscale, there is a significant difference between at least two time points, and the level of the IV accounts for approximately 2.7% of the variation in scores. Hyperactivity scores at T1 are significantly different from hyperactivity scores at T2, such that the mean of hyperactivity scores at T1 are significantly lower than T2. There is not, however, any significant difference between mean hyperactivity scores at T1 and T3, nor between mean hyperactivity scores at T2 and T3.

Associations Among Cognitive Abilities and Parent-Reported Attention/Impulse Regulation

The linear relationship among all variables were examined. Product-moment correlations among the variables are presented in Tables 3-5 at each time point.

T1. Participants ranged from 8-14 years of age. Bivariate correlations between WASI vocabulary score were moderate and significant with each of the other cognitive ability indices. Its strongest relationship was with the WASI matrix score, followed by Stroop interference score and then TMT Part B minus part A time. WASI matrix score, on the other hand, was more strongly associated with TMT Part B minus part A time than Stroop interference score at T1. Higher scores on the vocabulary and matrix reasoning subtests were both associated with lower Stroop and TMT scores (i.e., better inhibition and set-shifting, respectively).

Associations between SWAN scores and cognitive ability indices at T1 were all in the expected direction and the strongest correlations (although small to modest) were with the inattention subscale and composite score. Notably, WASI matrix reasoning was not significantly associated with SWAN composite score, nor any of its subscales. At T1, the strongest significant relationship was between the SWAN and TMT part B minus part A time, followed by Stroop interference score, and then WASI vocabulary.

As predicted, correlations among SWAN subscales (inattention, hyperactivity and impulsivity) were significant and large at all time points (see Tables 3-5). Regarding individual symptoms, hyperactivity and impulsivity were most strongly related.

Table 3

Correlations Among Variables at T1

	1	2	3	4	5	6	7	8
1. WASI Vocabulary	-	.51**	-.45**	-.37**	.19*	.15*	.16*	.18*
2. WASI Matrix		-	-.32**	-.39**	.13	.12	.09	.13
3. Stroop Interference			-	.37**	-.21**	-.18*	-.17*	-.21**
4. TMTb-a				-	-.30**	-.25**	-.27**	-.30**
5. SWAN Inattention					-	.76**	.68**	[.94**]
6. SWAN Hyperactive						-	.82**	[.92**]
7. SWAN Impulsivity							-	[.85**]
8. SWAN Composite								-

Note. ** p < .01, * p < .05; square brackets indicate part-whole relationships.

Time 2. At second follow up, participants were 10-18 years of age. Generally, the pattern of significant relationships among cognitive variables did not differ from T1 to T2. In terms of strength of relationships, contrary to what was seen at T1, vocabulary raw score was more strongly related to TMT performance than the Stroop, and the Stroop was more strongly related to matrix reasoning than TMT performance. Regarding relationships among SWAN and cognitive variables, the strongest relationships are still seen with the inattention subscale and composite score. WASI matrix reasoning was significantly associated with the SWAN at T2, whereas it was not at T1. Stroop interference score was no longer significantly associated with the SWAN.

Table 4

Correlations Among Variables at T2

	1	2	3	4	5	6	7	8
1. WASI Vocabulary	-	.40**	-.34*	-.36**	.23**	.20*	.15	.23**
2. WASI Matrix		-	-.37**	-.33**	.22**	.16*	.13	.20*
3. Stroop Interference			-	.24**	-.13	-.09	-.04	-.11
4. TMTb-a				-	-.28**	-.23**	-.20*	-.27**
5. SWAN Inattention					-	.77**	.72**	[.95**]
6. SWAN Hyperactive						-	.81**	[.92**]
7. SWAN Impulsivity							-	[.86**]
8. SWAN Composite								-

Note. ** p < .01, * p < .05; square brackets indicate part-whole relationships.

Time 3. At T3, participants were 13-20 years old. All cognitive ability indices remained significantly correlated with each other and presented in the expected directions. There no difference in the strength of the relationship between vocabulary scores and the two EF measures, however, matrix reasoning was more strongly related to the TMT than the Stroop. Correlations between cognitive ability indices and the SWAN composite score were significant and small to moderate. The inattention subscale appears to drive the relationship between the EF tasks (Stroop and TMT) and the SWAN, as neither the hyperactivity nor impulsivity scales are significantly related to EF tasks at T3.

Table 5

Correlations Among Variables at T3

	1	2	3	4	5	6	7	8
1. WASI Vocabulary	-	.36**	-.18*	-.18*	.29**	.25**	.32**	.31**
2. WASI Matrix		-	-.21*	-.30**	.26**	.26**	.28**	.29**
3. Stroop Interference			-	.20*	-.23**	-.12	-.16	-.20*
4. TMTb-a				-	-.34**	-.13	-.13	-.26**
5. SWAN Inattention					-	.74**	.67**	[.94**]
6. SWAN Hyperactive						-	.78**	[.91**]
7. SWAN Impulsivity							-	[.84**]
8. SWAN Composite								-

Note. ** p < .01, * p < .05; square brackets indicate part-whole relationships.

Overall, correlations among cognitive abilities were modest and in the expected direction. SWAN scores were highly correlated. Though bivariate correlations among cognitive ability indices and SWAN scores were generally significant, these relationships were small. Regarding SWAN composite score, the most consistent correlations were found with the TMT and WASI vocabulary scores, followed by the Stroop and WASI Matrices.

Temporal Relationships Between Cognitive Abilities and Parent-Reported Attention/ Impulse Regulation

Next, cross-lagged panel models were estimated to examine the temporal association between cognitive abilities and ratings of attention/impulse regulation, represented using the SWAN composite score. Model A explores the relationship between SWAN composite scores and WASI vocabulary raw scores at each time point. Models B, C and D were estimated using WASI matrix reasoning raw scores, Stroop interference scores and TMT Part B minus Part A scores at each time point, respectively. Model fit indices are presented in Table 6. Overall, the models fit the data adequately with acceptable values of CFI and SRMR, however, the TLI and

RMSEA are outside the values typically considered indicative of acceptable fit. Regression coefficients and paths of cross-lagged panel models of cognitive ability indices and parent-reported attention/ impulse regulation are shown in Figure 2.

Table 6

Fit of cross-lagged panel models

	Model A (Vocabulary)	Model B (Matrix)	Model C (Stroop)	Model D (TMT)
SRMR	.05	.05	.07	.05
RMSEA	.14	.13	.16	.12
CFI	.95	.95	.91	.94
TLI	.85	.85	.73	.83

Note. CFI Comparative Fit Index; *TLI* Tucker-Lewis Index; *RMSEA* Root Mean Square Error of Approximation; *SRMR* Standardized Root Mean Square Residual

Model A. Parent-reported attention/ impulse regulation at T1 was a significant predictor of parent-reported attention/ impulse regulation at T2 and ratings at T2 significantly predicted ratings at T3. Parent-reported attention/ impulse regulation at T1 and T2 did not significantly predict verbal ability at either follow-up time point. Similarly, verbal ability at T1 was a significant predictor of verbal ability at T2, which in turn was a significant predictor of verbal ability at T3 but did not significantly predict parent-reported attention/ impulse regulation at T2 and T3.

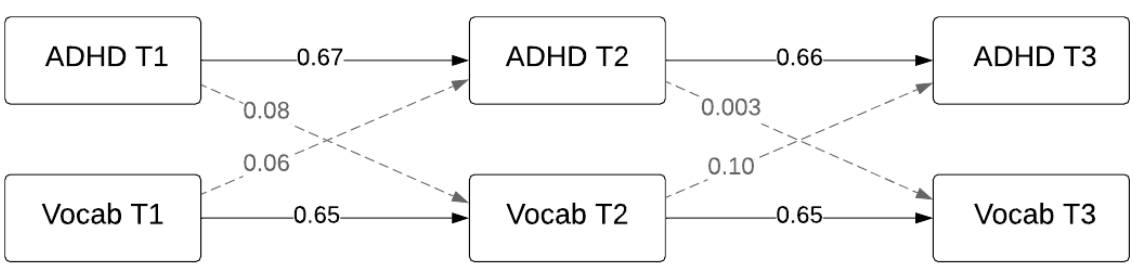
Model B. Parent-reported attention and hyperactivity/ impulsivity at T1 was a significant predictor of parent-reported attention/ impulse regulation at T2 and ratings at T2 significantly predicted ratings at T3. Parent-reported attention/impulse regulation at T1 also significantly predicted non-verbal ability at T2, controlling for T1 non-verbal ability. Non-verbal ability at T1 was a significant predictor of non-verbal ability at T2 and non-verbal ability at T2 significantly predicted non-verbal ability at T3. Additionally, non-verbal ability at T2 was a significant predictor of parent-reported attention/ impulse regulation at T3, controlling for T2 parent-reported attention/ impulse regulation.

Model C. Parent-reported attention/ impulse regulation at T1 was a significant predictor of parent-reported attention/ impulse regulation at T2 and ratings at T2 significantly predicted ratings at T3. Parent-reported attention/ impulse regulation at T1 and T2 did not significantly predict inhibition at either follow-up time point. Similarly, inhibition at T1 was a significant predictor of inhibition at T2, which in turn was a significant predictor of inhibition at T3 but did not significantly predict parent-reported attention/ impulse regulation at T2 and T3.

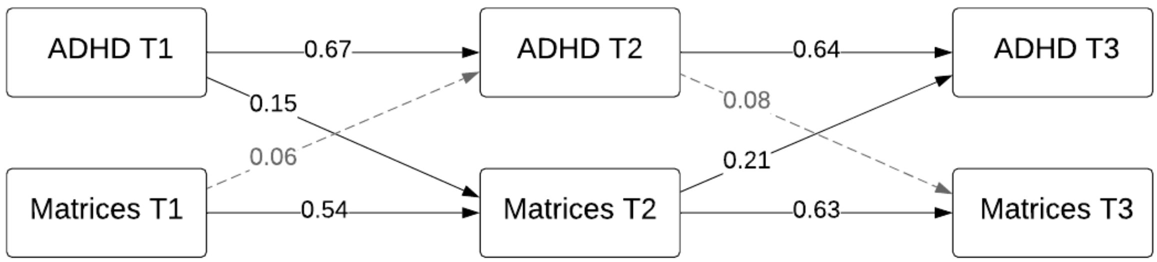
Model D. Parent-reported attention/ impulse regulation at T1 was a significant predictor of parent-reported attention/ impulse regulation at T2 and ratings at T2 significantly predicted ratings at T3. Parent-reported attention/ impulse regulation at T1 and T2 did not significantly predict set-shifting at either follow-up time point. Similarly, set-shifting at T1 was a significant predictor of set-shifting at T2, which in turn was a significant predictor of set-shifting at T3 but did not significantly predict parent-reported attention/ impulse regulation at T2 and T3.

Figure 2. Cross-lagged panel models using cognitive abilities and parent-reported attention/ impulse regulation

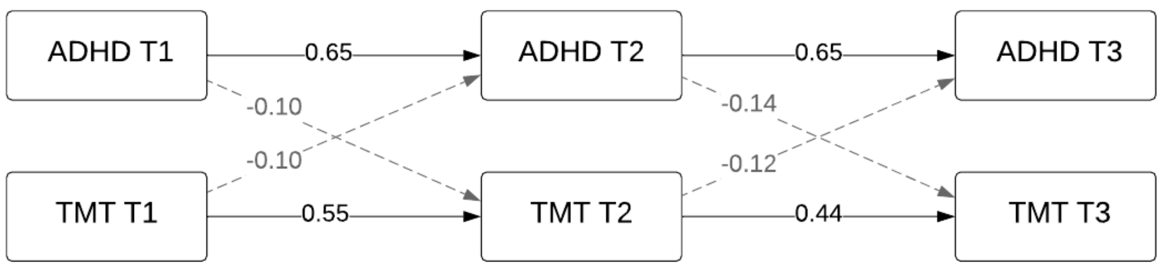
Model A - Vocab and parent-reported attention/ impulse regulation



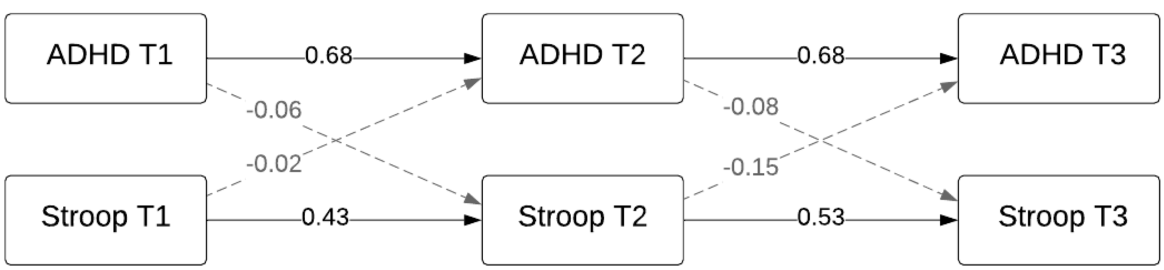
Model B - Matrix Reasoning and parent-reported attention/ impulse regulation



Model C – Trailmaking Part B minus Part A and parent-reported attention/ impulse regulation



Model D - Stroop Interference time and parent-reported attention/ impulse regulation



Note. Statistically significant paths are indicated using a solid black line, whereas paths that were tested but were not significant are depicted using a dashed grey line. An alpha level of .05 was used. *ADHD* refers to the SWAN Composite Score.

Table 7 reports the percentage of variance explained in each of the outcome variables (i.e., T2 and T3 variables) in the four models. Models explain a moderate amount of variance in EF indices at following time points, ranging from 20.2% to 34.6%. Moderate to large amounts of variance in task performance at following time points are explained in the four models, ranging from 34.2% to 45.8%. Finally, models explain moderate to large amount of variance in parent-reported attention/ impulse regulation at T2 and T3, ranging from 46.2% to 50.1%.

Table 7
Percentage of variance explained at each time point by the four models

	Outcome Variable	Variance Explained (%)
Model A	ADHD T2	46.6
	Vocab T2	45.2
	ADHD T3	47.5
	Vocab T3	42.8
Model B	ADHD T2	46.3
	Matrices T2	34.2
	ADHD T3	50.1
	Matrices T3	45.8
Model C	ADHD T2	47.5
	TMT T2	34.6
	ADHD T3	47.7
	TMT T3	23.9
Model D	ADHD T2	46.2
	Stroop T2	20.2
	ADHD T3	47.2
	Stroop T3	30.0

Discussion

In the present study, developmental associations among cognitive abilities and parent-reported attention/impulse regulation were examined longitudinally in a community sample of children and youth spanning 8-20 years of age. The analysis included: 1) mean comparisons of cognitive abilities (intelligence and EF tasks) and parent-reported attention/impulse regulation across time points, 2) an examination of the correlations among cognitive abilities with parent-reported attention/impulse regulation, and 3) an examination of the temporal relationship between cognitive abilities and parent-reported attention/impulse regulation. Based on the analysis of variances, there was no significant change in attention or impulsivity over time in this community sample. Hyperactivity displayed an inconsistent pattern, such that a there is a significant decrease in parent-reported hyperactivity from T1 to T2 but not from T1 to T3. Cognitive abilities, on the other hand, all improved over time. The correlational results displayed small to modest relations among cognitive abilities and parent-reported attention/impulse regulation. Last, in the cross-lagged panel models, each measure predicted itself at the following time point in addition to SWAN composite scores at T1 predicting matrix reasoning performance at T2, and matrix reasoning at T2 predicting SWAN composite scores at T3. No patterns emerged when the EF tasks and WASI vocabulary were included alongside parent-reported attention/impulse regulation.

Development of Cognitive Abilities and Parent-Reported Attention/Impulse Regulation

Overall, performance on cognitive ability tasks in our sample improved at each time point, indicating better performance with increasing age. The cognitive ability tasks included WASI vocabulary (an indicator of verbal ability), WASI matrices (an indicator of nonverbal ability), Stroop Interference time (an index of inhibition ability) and TMT Part B minus Part A (an index of set shifting ability). Verbal and nonverbal abilities improved from T1 to T2, and T2 to T3. This finding is in line with our understanding of verbal abilities which are a domain of global intelligence and correspond to verbal skills, instruction, and knowledge acquired through education (Skirbekk, 2004), and thus raw scores are expected to increase developmentally (Rizeq et al., 2017; Tucker-Drob, 2009). Regarding the EF tasks, inhibition improved significantly at each follow up, and set shifting improved significantly from T1 to T2 which is consistent with the reported EF improvements in childhood and adolescence (Carlozzi, Tulsky, Kail, &

Beaumont, 2013; Carlson, Zelazo, & Faja, 2013; Lehto et al., 2003; Tulsky et al., 2013; Zelazo et al., 2013; Zelazo et al., 2004; Zelazo et al., 2003).

In general, parent-reported attention/impulse regulation did not change significantly across time points. This apparent lack of developmental change is inconsistent with the body of research in clinical samples that suggests an overall decrease in ADHD symptom severity, particularly in the hyperactivity-impulsivity dimension (Biederman, Mick, & Faraone, 2000; Evans et al., 2013). Though parent-reported hyperactivity scores did increase significantly (i.e., fewer symptoms of hyperactivity) from T1 to T2, the significant change did not persist at T3 and the SWAN composite score did not show developmental change, which makes these results somewhat surprising. Lack of significant change in the attention dimension is somewhat less surprising. The results for inattention in the literature are less conclusive: some studies show a reduction in attention over time (Biederman et al., 2000; Evans et al., 2013) while others have reported these symptoms are relatively constant (Hart, Lahey, Loeber, Applegate, & Frick, 1995). In contrast, one recent study reported an increase in inattention from middle childhood to adolescence (Larsson, Dilshad, Lichtenstein, & Barker, 2011). Similarly, community-based studies also demonstrate a general decline of ADHD-like behaviours across age, with inattentive behaviours persisting more than hyperactive/ impulsive behaviours (Döpfner et al., 2015; Holbrook et al., 2016; Tsai, Chen, Lin, & Gau, 2017).

One possible explanation for the lack of change in parent-reported attention/impulse regulation over time is that there was a ceiling effect on change in symptoms in this community sample, such that participants' attention and impulse regulation skills were relatively strong at baseline and had little room to improve. However, this is unlikely in the current sample given the wide range in baseline SWAN scores (29-121 of a possible 18-126 range). Alternatively, the use of the SWAN to measure developmental change may not be appropriate which is discussed below.

Associations Among Cognitive Abilities

Cognitive ability indices were all significantly correlated with each other at each time point. Correlations were all in the expected direction and small to moderate in size. Although there is support for a three-factor EF task model originally proposed by Miyake et al. (2000), including inhibition, set shifting and working memory, investigators have also noted substantial overlap between EF tasks and intelligence, particularly when they are measured alongside each other (Arffa, 2007; Brydges, Fox, Reid, & Anderson, 2014; Jewsbury et al., 2016; Salthouse, Atkinson, & Berish, 2003). This finding is also consistent with previous work by Salthouse and colleagues (Salthouse & Davis, 2006) where significant positive correlations were rated between measures of nonverbal intelligence with EF measures across all age groups.

The modest relations between intelligence and the two EFs measured in this study may initially seem surprising; however, much of the evidence for strong relationships between EFs and intelligence comes from clinical and aging populations (Brydges et al., 2012; Salthouse et al., 2003; Salthouse, Fristoe, McGuthry, & Hambrick, 1998). Indeed, the larger correlations seen in lower functioning populations suggest that these abilities are less differentiated than in the general population. Despite the strong connections between conceptual theories of intelligence and EF constructs, the heterogeneity of the skills required for both and the diversity of the performance-based tasks have maintained the debate over the exact aspects of EF that are actually measured by intelligence tests (Ardila et al., 2000; Friedman et al., 2006). Although the current data do not speak directly to the associations between EFs and intelligence in clinical or lower functioning populations, it is possible that areas relevant to aspects of intelligence and EF have been impacted, which is driving the stronger associations between the two in this literature. That is, that the injury or etiology leading to lower functioning itself, might explain the stronger associations and less differentiation of these abilities. It follows that greater differentiation (i.e., weaker associations) might be seen in a community sample.

Associations of Cognitive Abilities with Parent-Reported Attention/Impulse Regulation

Contrary to what was hypothesized, the cognitive measures were not all significantly related to SWAN parent ratings at each time point and where correlations were significant, they were generally small. Associations between WASI measures (Vocabulary and Matrix Reasoning) and SWAN scores had greater consistency across time than those between the EF tasks and SWAN scores. The strength of the relationship between WASI measures and SWAN scores were positive, inconsistently significant and small. Regarding the EF tasks, inhibition (Stroop interference score) was negatively related to the SWAN parent ratings, such that better attention and impulse regulation was associated with lower interference scores (i.e., better inhibition). Set-shifting (TMT Part B minus Part A) was negatively and significantly correlated with the SWAN at all three time points. Though in the expected direction, these small and inconsistent correlations are somewhat surprising, given that the relationship between EF and ADHD ratings are well established in the clinical literature. Numerous studies have shown that ADHD symptoms are moderately to highly correlated with and predictive of EF deficits (Pievsky & McGrath, 2018; Silverstein et al., 2018; Willcutt et al., 2005). Yet, our finding is consistent with the variable and modest correlations reported between performance-based and rating measures of executive function. Although the SWAN measures parent-reported attention/ impulse regulation, it shares many features with parent reports of executive function, such as the Brief Rating Inventory for Executive Function (BRIEF; Gioia, Isquith, Guy, & Kenworth, 2013).

A review revealed only 24% of relevant correlations reported across studies included were statistically significant, and the overall median correlation was .19, which is modest at best (Toplak et al., 2013). EF performance is considered in many theoretical models to be a core component of ADHD (Barkley, 1997; Nigg, 2000, 2001; Pennington & Ozonoff, 1996) and this relationship has been shown to be modest in ADHD samples where there is somewhat restricted range in ADHD symptoms. Here, we test the relationship with a much broader range of ADHD-related symptoms in a community sample. The range in ADHD symptoms was substantial (SWAN composite score ranged from 29- 121) and still, the relationship is small to modest. It was expected that the correlation between cognitive abilities and SWAN ratings would have been higher in our current community sample, and several explanations should be considered for these small, modest associations.

One explanation for the small to moderate correlations between cognitive abilities and SWAN ratings is that cognitive abilities displayed developmental change, but SWAN parent ratings did not display change with developmental level. There are several methodological challenges to measuring age-related change in SWAN ratings across development. This dilemma is addressed in various ways by common behavioural rating scales. The Behavior Assessment System for Children (BASC; Reynolds & Kamphaus, 1992), for example, uses multiple forms (i.e., child and adolescent forms) rather than a single form to provide developmentally-sensitive indicators of psychopathology. Yet, the use of age-appropriate test forms may preclude a robust estimation of developmental effects due to differences in items on the forms. In their comparison of the child and adolescent parent forms of the BASC, Barbot and colleagues note that it fails to achieve a minimal level of measurement invariance (i.e., that the same construct is being measured across groups) needed for the investigation of developmental change (Barbot, Hein, Luthar, & Grigorenko, 2014).

Instead, some scales such as the Conners Comprehensive Behaviour Rating Scales (CBRS; Conners, 2008) and the ADHD Rating Scale-5 for Children and Adolescents (DuPaul, Power, Anastopoulos, & Reid, 2016), use one form for school-aged youth but provide norms based on age to address developmental changes. With respect to the CBRS, age of the youth was found to affect the majority of the scales, though the size of the significant effects were small (Conners, 2008). Notably, parents rated younger youth as having significantly more problems than older youth on the Hyperactivity/ Impulsivity scale (Conners, 2008). Similarly, the ADHD Rating Scale-5 for Children and Adolescents manual reports significant main effects of age, such that the youngest children (ages 5-7) received higher parent-reported scores than children in the oldest age group (ages 14-17) on total ADHD score, and children in the oldest age group were rated significantly lower than children in the two youngest groups (ages 5-10) on Hyperactivity/ Impulsivity (DuPaul et al., 2016).

There is also some evidence of age effects on non-normed behaviour rating scales, such as the Strengths and Difficulties Questionnaire (SDQ) and the Swanson, Nolan, and Pelham, IV (SNAP-IV; Swanson et al., 2001). Regarding the SDQ, diverse normative data and psychometric studies have reported a similar descending tendency of parent ratings with age, particularly with respect to hyperactivity and inattention (Du, Kou, & Coghill, 2008; Matsuishi et al., 2008; Mellor, 2005; Moriwaki & Kamio, 2014; van Widenfelt, Goedhart, Treffers, & Goodman, 2003; Woerner, Becker, & Rothenberger, 2004), although no age effect was found in community samples in Holland (Muris, Meesters, & van den Berg, 2003) or Hong Kong (Lai et al., 2010) or in an epidemiological sample in the United Kingdom (Copeland et al., 2013). Less normative data are available for the SNAP-IV, however, estimates from a longitudinal study examining psychometric properties of the MTA version of the SNAP-IV showed a small effect size for parent inattention ratings comparing 8- to 10-year-olds and 5- to 7-year-olds with 11-year-olds, with higher ratings for the oldest group (Bussing et al., 2008).

The SWAN does not have normative data available and to the best of our knowledge, no research has been done specifically investigating age effects for this scale. One study comparing the SWAN to another ADHD rating scale notes age-related differences, whereby younger children were rated as more impaired on the SWAN than older ones (Hay et al., 2007). This holds important methodological significance as parents are asked to report their child's behaviour relative to other children of the same age, but there is no developmental reference point. When parents rate how well their child can sustain attention, they may say "above average" when the child is eight, but also indicate the same rating at age ten. Based on normative data from other behavioural rating scales, developmental change is expected. Indeed, it is unclear if we can reliably measure any developmental change with such a scale, especially when the scale is given at a different period of development and different context. There is an important measurement issue here that may prevent researchers from measuring the association between cognitive ability and temperamental (i.e., behavior rating) aspects of self-regulation. It is thus important to consider whether the relationships (or lack thereof) between parent-reported attention/impulse regulation and cognitive variables in this study was influenced by the way in which the former construct was measured.

Directional Influences of Cognitive Abilities and Parent-Reported Attention/Impulse Regulation Over Time

The final analysis in this study tested the temporal association between cognitive abilities and ratings of attention/impulse regulation. It is reported here that each cognitive ability index significantly predicted itself at the following time point, and parent-reported attention/impulse regulation predicted the same ratings at the following time point as well. While no patterns emerged in the WASI vocabulary, Stroop Interference or TMT part B minus part A models, the WASI matrix reasoning model showed a unique pattern. Parent-reported attention/impulse regulation at T1 also significantly predicted non-verbal ability at T2, controlling for T1 non-verbal ability. Additionally, non-verbal ability at T2 was a significant predictor of parent-reported attention/impulse regulation at T3, controlling for T2 parent-reported attention/impulse regulation.

Considering this finding, non-verbal ability in late childhood can be accounted for, in part, by attention/impulse regulation earlier in development. Non-verbal ability in late childhood, in turn, contributes to the development of controlling attention, behaviour, and impulses in adolescence. The amount of variance explained in this model was relatively large, 34.2-50.1%, which suggests that the given predictors account for considerable amount of the variance in the given outcome. These results represent conservative estimates of the respective linear relationship as they control for the outcome measure at the previous time point. Of course, other cognitive indices or other processes which are not included in the model, may also have important effects on these relationships across development and fit-indices caution against drawing definitive conclusions.

One speculation for these results is that there is a transactional relationship between behavioural regulation and tasks involving relational reasoning, a component of fluid reasoning (Ferrer, O'Hare, & Bunge, 2009). Fluid reasoning, broadly, is the ability to manipulate stimuli to reason, plan, and problem solve using attentional, inhibition, working memory, and cognitive perceptual skills (Cho et al., 2010; Morrison et al., 2004; Waltz et al., 1999). The fact that attention and inhibitory control play an important role in successful fluid reasoning and that these are areas of deficit in ADHD (Nigg, Blaskey, Huang-Pollock, & Rappley, 2002; Nigg, Blaskey, Stawicki, & Sachek, 2004; Willcutt et al., 2005), suggests that we might anticipate behavioral differences in individuals with higher parent-reported attention/ impulse regulation on tasks assessing fluid reasoning. However, replication is necessary to fully understand the directional influences between these constructs and infer causality.

Summary of Conclusions and Implications

The converging results of the analyses suggest that many cognitive abilities (including intelligence and EFs) show developmental effects, but parent ratings of attention/impulse regulation on the SWAN do not. Most explanatory models for ADHD have focused on EF deficits (Willcutt et al., 2005), which have led to understanding EF as critical to the developmental improvement in attention/impulse regulation. Nevertheless, the numerous inconsistencies in the literature and the lack of developmental change in our study raise important questions about our conceptualization of and how we attempt to measure the interface between cognitive performance and ADHD-related behaviours. Halperin and Schulz (2006) proposed an alternative theory regarding the relationship between EF and ADHD symptoms: perhaps EFs are minimally involved in the early emergence of inattention, impulsivity, and hyperactivity, but are actually able to moderate these behaviours. This hypothesis posits that ADHD is primarily a noncortical disorder arising from basal ganglia and cerebellum dysfunction that persists across the lifespan, even in individuals who experience symptom resolution. Rather, prefrontal neurocognitive mechanisms (i.e., EF) can moderate the expression of poor self-regulation behaviours. Halperin and Schulz's model predicts that subcortical processes, such as processing speed, will remain impaired even in individuals who no longer meet the symptom criteria of ADHD and are thus a core feature of ADHD. This model also predicts that the children who show the greatest neurocognitive improvement, particularly on tasks reliant on the prefrontal cortex (e.g., high-level mental effort/executive function tasks), will also show the greatest reduction in ADHD symptomatology over time.

Cross-sectional studies comparing the executive performance of children who continue to meet criteria for ADHD (i.e., persisters) and those who no longer meet criteria for ADHD (i.e., partial or complete remitters) suggest that persisters have greater deficits across several executive domains, including attentional control (Barkley, Fischer, Smallish, & Fletcher, 2002; Bédard et al., 2010), set shifting (Halperin et al., 2008; Murray et al., 2017; Robinson & Tripp, 2013), goal setting and information processing (Murray et al., 2017; Robinson & Tripp, 2013). In their recent systematic review of the literature however, van Lieshout and colleagues (2013) concluded that neither higher nor lower neurocognitive functions reliably differentiate persistent from remitting ADHD, with both groups showing poorer performance than controls (Van Lieshout et al., 2013). The finding that ADHD symptom remission was not predicted by neurocognitive functioning was thus interpreted as evidence against Halperin and Schulz's model.

These results provide insight into the relationships and underlying cognitive processes among some of the most utilized measures of cognitive ability as well as parent-reported attention/impulse regulation (Miyake & Friedman, 2012). Consistent with previous research and theory, cognitive indices of intelligence and EF tasks showed developmental improvements (Cattell, 1963; Deary, Whalley, Lemmon, Crawford, & Starr, 2000; Jurado & Rosselli, 2007;

Salthouse & Davis, 2006). Across all analyses conducted, results did not suggest a strong or predictive relationship between cognitive abilities (particularly EF) and parent-reported attention and hyperactivity/impulsivity. This is in line with the discordant results in the literature between parent-report and experimental measures of executive function (Toplak et al., 2013). These findings, however, are not consistent with long-standing research that suggests attention problems during childhood may predict executive dysfunction later in development (Friedman et al., 2007; Miller, Nevado-Montenegro, & Hinshaw, 2012). Unique among these relationships was that of nonverbal ability and reported attention and hyperactivity/ impulsivity. Over the course of development, it appears that these constructs may be importantly related and predictive of each other at different stages.

The use of a community sample uniquely allowed for the exploration of the relation between cognitive abilities and parent-reported attention/impulse regulation using the full range of symptoms, and avoided referral-bias which is known to confound studies with clinical samples. Moreover, this is in line with the conceptualization of attention and hyperactivity/impulsivity problems in ADHD as a continuum (see: Levy, Hay, McStephen, Wood, & Waldman, 1997; Lubke, Hudziak, Derks, van Bijsterveldt, & Boomsma, 2009) rather than a discrete category. Indeed, the characterization of ADHD symptoms in the community is an important public health activity as studies of typically developing children can give us valuable information about cognitive functioning in clinical groups. A strength of this study is its methodological contribution to both the developmental and clinical literatures. As convergent measures of SR, the small and variable relationships between cognitive abilities and parent-reported attention/impulse regulation raise important questions about the reliability and validity of these measures, particularly the developmental sensitivity of the SWAN ratings.

Understanding these different indicators of SR may also inform the development of early prevention and targeted treatment strategies, inform educators on what to expect within the classroom, as well as efforts to educate parents on what to expect from their child's development of regulation over time, especially in at-risk and ADHD populations.

Future Directions and Limitations

The unique findings and important methodological implications of this study are discussed in light of certain limitations. This study focused on two robust indicators of intelligence (nonverbal and verbal ability) and two of three defining EF processes as identified by Miyake and colleagues (2000), however, it is important to replicate the results with a larger set of measures. Although four common and representative measures of cognitive abilities were used, there are many more cognitive ability measures utilized in clinical and research settings that might reflect different dimensions and processes than the ones used in the current analyses. This study also used one measure of parent-reported attention and hyperactivity/ impulsivity, which may lack developmental sensitivity. Future studies should implement a multi-informant assessment of cognitive and behavioural regulation for a more reliable and valid representation of these constructs.

In conclusions, results obtained from the analyses conducted in this study supported the developmental nature of cognitive abilities in younger populations, and highlighted the challenges associated with measuring the relations among cognitive abilities and behavioural regulation. The current study's lack of developmental differences in ratings of attention and hyperactivity and impulsivity and the inconsistent findings regarding EF and ADHD symptoms in the literature more broadly draw in to question our ability to adequately capture the developmental relationship between behavioural and cognitive aspects of SR with these measures. Moreover, it has further emphasized the importance of considering development when interpreting neuropsychological processes and their association with parent-reported attention/impulse regulation.

References

Adler, L. A., Faraone, S. V., Spencer, T. J., Berglund, P., Alperin, S., & Kessler, R. C. (2017). The structure of adult ADHD. *Int J Methods Psychiatr Res, 26*(1). doi:10.1002/mpr.1555

American Psychiatric, A. (2013). *Diagnostic and Statistical Manual of Mental Disorders, 5th Ed. (DSM-V)*. Arlington, VA: American Psychiatric Association.

Anderson, P. (2002). Assessment and development of executive function (EF) during childhood. *Child Neuropsychol., 8*(2), 71-82. doi:10.1076/chin.8.2.71.8724

Arbuthnott, K., & Frank, J. (2000). Trail making test, part B as a measure of executive control: validation using a set-switching paradigm. *J Clin Exp Neuropsychol, 22*(4), 518-528. doi:10.1076/1380-3395(200008)22:4;1-0;ft518

Ardila, A., Pineda, D., & Rosselli, M. (2000). Correlation between intelligence test scores and executive function measures. *Archives of Clinical Neuropsychology, 15*(1), 31-36.

Arffa, S. (2007). The relationship of intelligence to executive function and non-executive function measures in a sample of average, above average, and gifted youth. *Archives of Clinical Neuropsychology, 22*(8), 969-978. doi:10.1016/j.acn.2007.08.001

Arnett, A. B., Pennington, B. F., Friend, A., Willcutt, E. G., Byrne, B., Samuelsson, S., & Olson, R. K. (2013). The SWAN captures variance at the negative and positive ends of the ADHD symptom dimension. *J Atten Disord, 17*(2), 152-162. doi:10.1177/1087054711427399

Baddeley, A. D. (2000). The episodic buffer: a new component of working memory? *Trends Cogn Sci, 4*(11), 417-423.

Baddeley, A. D., & Hitch, G. J. (1994). Developments in the concept of working memory. *Neuropsychology, 8*(4), 485-493. doi:10.1037/0894-4105.8.4.485

Banich, M. T. (2009). Executive Function: The Search for an Integrated Account. *Curr. Dir. Psychol. Sci., 18*(2), 89-94. doi:10.1111/j.1467-8721.2009.01615.x

Barbot, B., Hein, S., Luthar, S. S., & Grigorenko, E. L. (2014). Capturing Age-group Differences and Developmental Change with the BASC Parent Rating Scales. *Journal of applied developmental psychology, 35*(4), 294-303. doi:10.1016/j.appdev.2014.04.003

Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: constructing a unifying theory of ADHD. *Psychol. Bull., 121*(1), 65-94. doi:10.1037/0033-2909.121.1.65

Barkley, R. A., & Fischer, M. (2011). Predicting impairment in major life activities and occupational functioning in hyperactive children as adults: self-reported executive function (EF) deficits versus EF tests. *Dev. Neuropsychol., 36*(2), 137-161. doi:10.1080/87565641.2010.549877

Barkley, R. A., & Murphy, K. R. (2010). Impairment in occupational functioning and adult ADHD: the predictive utility of executive function (EF) ratings versus EF tests. *Arch Clin Neuropsychol, 25*(3), 157-173. doi:10.1093/arclin/acq014

Biederman, J., Mick, E., & Faraone, S. V. (2000). Age-dependent decline of symptoms of attention deficit hyperactivity disorder: impact of remission definition and symptom type. *Am J Psychiatry, 157*(5), 816-818. doi:10.1176/appi.ajp.157.5.816

Biederman, J., Petty, C., Fried, R., Fontanella, J., Doyle, A. E., Seidman, L. J., & Faraone, S. V. (2006). Impact of psychometrically defined deficits of executive functioning in adults with attention deficit hyperactivity disorder. *Am J Psychiatry, 163*(10), 1730-1738. doi:10.1176/ajp.2006.163.10.1730

Biederman, J., Petty, C. R., Ball, S. W., Fried, R., Doyle, A. E., Cohen, D., . . . Faraone, S. V. (2009). Are cognitive deficits in attention deficit/hyperactivity disorder related to the course of the disorder? A prospective controlled follow-up study of grown up boys with persistent and remitting course. *Psychiatry Res., 170*(2-3), 177-182. doi:10.1016/j.psychres.2008.09.010

Blair, C., Raver, C. C., & Finegood, E. D. (2016). Self-regulation and developmental psychopathology: Experiential canalization of brain and behavior. In D. Cicchetti (Ed.), *Developmental Psychopathology* (pp. 484–522): John Wiley & Sons.

Bollen, K. A., & Curran, P. J. (2006). *Latent curve models: A structural equation approach*. Hoboken, NJ: Wiley.

Brosseau-Liard, P. E., & Savalei, V. (2014). Adjusting Incremental Fit Indices for Nonnormality. *Multivariate Behav Res, 49*(5), 460-470. doi:10.1080/00273171.2014.933697

Brosseau-Liard, P. E., Savalei, V., & Li, L. (2012). An Investigation of the Sample Performance of Two Nonnormality Corrections for RMSEA. *Multivariate Behav Res, 47*(6), 904-930. doi:10.1080/00273171.2012.715252

Brydges, C. R., Fox, A. M., Reid, C. L., & Anderson, M. (2014). The differentiation of executive functions in middle and late childhood: A longitudinal latent-variable analysis. *Intelligence, 47*, 34-43.

Brydges, C. R., Reid, C. L., Fox, A. M., & Anderson, M. (2012). A unitary executive function predicts intelligence in children. *Intelligence, 40*(5), 458-469.

Bunge, S. A., & Zelazo, P. D. (2006). A Brain-Based Account of the Development of Rule Use in Childhood. *Curr. Dir. Psychol. Sci., 15*(3), 118-121. doi:10.1111/j.0963-7214.2006.00419.x

Bussing, R., Fernandez, M., Harwood, M., Wei, H., Garvan, C. W., Eyberg, S. M., & Swanson, J. M. (2008). Parent and teacher SNAP-IV ratings of attention deficit hyperactivity disorder symptoms: psychometric properties and normative ratings from a school district sample. *Assessment, 15*(3), 317-328. doi:10.1177/1073191107313888

Carlozzi, N. E., Tulsky, D. S., Kail, R. V., & Beaumont, J. L. (2013). VI. NIH Toolbox Cognition Battery (CB): measuring processing speed. *Monographs of the Society for Research in Child Development, 78*(4), 88-102.

Carlson, S. M., Zelazo, P. D., & Faja, S. (2013). Executive Function. In P. D. Zelazo (Ed.), *The Oxford Handbook of Developmental Psychology, Vol. 1: Body and Mind*: Oxford University Press.

Casey, B. J., Giedd, J. N., & Thomas, K. M. (2000). Structural and functional brain development and its relation to cognitive development. *Biol. Psychol., 54*(1-3), 241-257. doi:10.1016/S0301-0511(00)00058-2

Cattell, R. B. (1963). Theory of fluid and crystallized intelligence: A critical experiment. *Journal of educational psychology, 54*(1), 1.

Cattell, R. B. (1971). *Abilities: Their structure, growth and action*. Boston: Houghton-Mifflin.

Cho, S., Moody, T. D., Fernandino, L., Mumford, J. A., Poldrack, R. A., Cannon, T. D., . . . Holyoak, K. J. (2010). Common and dissociable prefrontal loci associated with component mechanisms of analogical reasoning. *Cereb Cortex, 20*(3), 524-533. doi:10.1093/cercor/bhp121

Conners, C. K. (2008). *Conners Comprehensive Behaviour Rating Scales (Conners CBRS): Manual*. Toronto, Canada: Multi-Health Systems Inc.

Copeland, W. E., Adair, C. E., Smetanin, P., Stiff, D., Briante, C., Colman, I., . . . Angold, A. (2013). Diagnostic transitions from childhood to adolescence to early adulthood. *J Child Psychol Psychiatry, 54*(7), 791-799. doi:10.1111/jcpp.12062

de Ridder, D. T., Lensvelt-Mulders, G., Finkenauer, C., Stok, F. M., & Baumeister, R. F. (2012). Taking stock of self-control: a meta-analysis of how trait self-control relates to a wide range of behaviors. *Pers Soc Psychol Rev, 16*(1), 76-99. doi:10.1177/1088868311418749

Deary, I. J., Penke, L., & Johnson, W. (2010). The neuroscience of human intelligence differences. *Nature reviews neuroscience, 11*(3), 201. doi:10.1038/nrn2793

Deary, I. J., Whalley, L. J., Lemmon, H., Crawford, J., & Starr, J. M. (2000). The stability of individual differences in mental ability from childhood to old age: follow-up of the 1932 Scottish Mental Survey. *Intelligence, 28*(1), 49-55.

Demetriou, A. (2000). Organization and development of self-understanding and self-regulation: Toward a general theory *Handbook of self-regulation* (pp. 209-251): Elsevier.

Dennis, M., Francis, D. J., Cirino, P. T., Schachar, R., Barnes, M. A., & Fletcher, J. M. (2009). Why IQ is not a covariate in cognitive studies of neurodevelopmental disorders. *J Int Neuropsychol Soc, 15*(3), 331-343. doi:10.1017/S1355617709090481

Diamantopoulou, S., Rydell, A.-M., Thorell, L. B., & Bohlin, G. (2007). Impact of Executive Functioning and Symptoms of Attention Deficit Hyperactivity Disorder on Children's Peer Relations and School Performance. *Developmental neuropsychology, 32*(1), 521-542. doi:10.1080/87565640701360981

Diamond, A. (2002). Normal Development of Prefrontal Cortex from Birth to Young Adulthood: Cognitive Functions, Anatomy, and Biochemistry *Principles of Frontal Lobe Function* (pp. 466-503). New York: Oxford University Press.

Diamond, A. (2013). Executive Functions. *Annu. Rev. Psychol., 64*(1), 135-168. doi:10.1146/annurev-psych-113011-143750

Döpfner, M., Hautmann, C., Görtz-Dorten, A., Klasen, F., Ravens-Sieberer, U., & group, B. s. (2015). Long-term course of ADHD symptoms from childhood to early adulthood in a community sample. *Eur. Child Adolesc. Psychiatry, 24*(6), 665-673. doi:10.1007/s00787-014-0634-8

Du, Y., Kou, J., & Coghill, D. (2008). The validity, reliability and normative scores of the parent, teacher and self report versions of the Strengths and Difficulties Questionnaire in China. *Child Adolesc Psychiatry Ment Health, 2*(1), 8. doi:10.1186/1753-2000-2-8

DuPaul, G. J., Power, T. J., Anastopoulos, A. D., & Reid, R. (2016). *ADHD Rating Scale-5 for Children and Adolescents: Checklists, norms, and clinical interpretation*. New York, NY: The Guilford Press.

Durston, S., Davidson, M. C., Tottenham, N., Galvan, A., Spicer, J., Fossella, J. A., & Casey, B. J. (2006). A shift from diffuse to focal cortical activity with development. *Dev. Sci., 9*(1), 1-8. doi:10.1111/j.1467-7687.2005.00454.x

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. (1999). Working memory, short-term memory, and general fluid intelligence: a latent-variable approach. *J Exp Psychol Gen, 128*(3), 309-331. doi:10.1037/0096-3445.128.3.309

Engelhardt, L. E., Mann, F. D., Briley, D. A., Church, J. A., Harden, K. P., & Tucker-Drob, E. M. (2016). Strong genetic overlap between executive functions and intelligence. *J Exp Psychol Gen, 145*(9), 1141-1159. doi:10.1037/xge0000195

Evans, S. W., Brady, C. E., Harrison, J. R., Bunford, N., Kern, L., State, T., & Andrews, C. (2013). Measuring ADHD and ODD symptoms and impairment using high school teachers' ratings. *J Clin Child Adolesc Psychol, 42*(2), 197-207. doi:10.1080/15374416.2012.738456

Faraone, S. V., Asherson, P., Banaschewski, T., Biederman, J., Buitelaar, J. K., Ramos-Quiroga, J. A., . . . Franke, B. (2015). Attention-deficit/hyperactivity disorder. *Nat Rev Dis Primers, 1*, 15020. doi:10.1038/nrdp.2015.20

Ferrer, E., O'Hare, E. D., & Bunge, S. A. (2009). Fluid reasoning and the developing brain. *Front Neurosci, 3*(1), 46-51. doi:10.3389/neuro.01.003.2009

Frazier, T. W., Demaree, H. A., & Youngstrom, E. A. (2004). Meta-analysis of intellectual and neuropsychological test performance in attention-deficit/hyperactivity disorder. *Neuropsychology, 18*(3), 543-555. doi:10.1037/0894-4105.18.3.543

Frick, M. A., Bohlin, G., Hedqvist, M., & Brocki, K. C. (2018). Temperament and Cognitive Regulation During the First 3 Years of Life as Predictors of Inattention and Hyperactivity/Impulsivity at 6 Years. *J Atten Disord*, 1087054718804342. doi:10.1177/1087054718804342

Fried, R., Chan, J., Feinberg, L., Pope, A., Woodworth, K. Y., Faraone, S. V., & Biederman, J. (2016). Clinical correlates of working memory deficits in youth with and without ADHD: A controlled study. *J Clin Exp Neuropsychol, 38*(5), 487-496. doi:10.1080/13803395.2015.1127896

Friedman, N. P., Haberstick, B. C., Willcutt, E. G., Miyake, A., Young, S. E., Corley, R. P., & Hewitt, J. K. (2007). Greater attention problems during childhood predict poorer executive functioning in late adolescence. *Psychol Sci, 18*(10), 893-900. doi:10.1111/j.1467-9280.2007.01997.x

Friedman, N. P., & Miyake, A. (2017). Unity and diversity of executive functions: Individual differences as a window on cognitive structure. *Cortex*, *86*, 186-204. doi:10.1016/j.cortex.2016.04.023

Friedman, N. P., Miyake, A., Corley, R. P., Young, S. E., DeFries, J. C., & Hewitt, J. K. (2006). Not all executive functions are related to intelligence. *Psychological science, 17*(2), 172-179.

Gioia, G. A., & Isquith, P. K. (2004). Ecological assessment of executive function in traumatic brain injury. *Dev. Neuropsychol., 25*(1-2), 135-158. doi:10.1080/87565641.2004.9651925

Gioia, G. A., Isquith, P. K., Guy, S. C., & Kenworth, L. (2013). *The Behavior Rating Inventory of Executive Function (BRIEF)*: WPS.

Gottfredson, L. S. (1997). Why g matters: The complexity of everyday life. *Intelligence*, *24*(1), 79-132. doi:10.1016/S0160-2896(97)90014-3

Halperin, J. M., Trampush, J. W., Miller, C. J., Marks, D. J., & Newcorn, J. H. (2008). Neuropsychological outcome in adolescents/young adults with childhood ADHD: profiles of persisters, remitters and controls. *J. Child Psychol. Psychiatry, 49*(9), 958-966. doi:10.1111/j.1469-7610.2008.01926.x

Hart, E. L., Lahey, B. B., Loeber, R., Applegate, B., & Frick, P. J. (1995). Developmental change in attention-deficit hyperactivity disorder in boys: a four-year longitudinal study. *J Abnorm Child Psychol, 23*(6), 729-749.

Hay, D. A., Bennett, K. S., Levy, F., Sergeant, J., & Swanson, J. (2007). A twin study of attention-deficit/hyperactivity disorder dimensions rated by the strengths and weaknesses of ADHD-symptoms and normal-behavior (SWAN) scale. *Biol Psychiatry, 61*(5), 700-705. doi:10.1016/j.biopsych.2006.04.040

Hebb, D. O. (1939). Intelligence in man after large removals of cerebral tissue: report of four left frontal lobe cases. *The Journal of General Psychology, 21*(1), 73-87.

Hebb, D. O., & Penfield, W. (1940). Human behavior after extensive bilateral removal from the frontal lobes. *Archives of Neurology & Psychiatry, 44*(2), 421-438.

Himelstein, J., Newcorn, J. H., & Halperin, J. M. (2000). The neurobiology of attention-deficit hyperactivity disorder. *Front. Biosci., 5*, D461-478.

Holbrook, J. R., Cuffe, S. P., Cai, B., Visser, S. N., Forthofer, M. S., Bottai, M., . . . McKeown, R. E. (2016). Persistence of Parent-Reported ADHD Symptoms From Childhood Through Adolescence in a Community Sample. *J. Atten. Disord., 20*(1), 11-20. doi:10.1177/1087054714539997

Hoogman, M., Bralten, J., Hibar, D. P., Mennes, M., Zwiers, M. P., Schweren, L. S. J., . . . Franke, B. (2017). Subcortical brain volume differences in participants with attention deficit hyperactivity disorder in children and adults: a cross-sectional mega-analysis. *Lancet Psychiatry, 4*(4), 310-319. doi:10.1016/S2215-0366(17)30049-4

Jacobson, L. A., Williford, A. P., & Pianta, R. C. (2011). The role of executive function in children's competent adjustment to middle school. *Child Neuropsychology, 17*(3), 255-280. doi:10.1080/09297049.2010.535654

Jersild, A. T. (1927). Mental set and shift. *Archives of Psychology, 14, 89*, 81-81.

Jewsbury, P. A., Bowden, S. C., & Strauss, M. E. (2016). Integrating the switching, inhibition, and updating model of executive function with the Cattell-Horn-Carroll model. *J Exp Psychol Gen, 145*(2), 220-245. doi:10.1037/xge0000119

Jurado, M. B., & Rosselli, M. (2007). The elusive nature of executive functions: a review of our current understanding. *Neuropsychology review, 17*(3), 213-233.

Kearney, M. (2017). Cross-Lagged Panel Analysis. In M. R. Allen (Ed.), *Sage Encyclopedia of Communication Research Methods*. Thousand Oaks, California: SAGE Publications, Inc.

Kochanska, G., Coy, K. C., & Murray, K. T. (2001). The development of self-regulation in the first four years of life. *Child development, 72*(4), 1091-1111.

Kuntsi, J., Andreou, P., Ma, J., Börger, N. A., & van der Meere, J. J. (2005). Testing assumptions for endophenotype studies in ADHD: reliability and validity of tasks in a general population sample. *BMC Psychiatry, 5*, 40. doi:10.1186/1471-244X-5-40

Lai, K. Y., Luk, E. S., Leung, P. W., Wong, A. S., Law, L., & Ho, K. (2010). Validation of the Chinese version of the strengths and difficulties questionnaire in Hong Kong. *Soc Psychiatry Psychiatr Epidemiol, 45*(12), 1179-1186. doi:10.1007/s00127-009-0152-z

Lakes, K. D., Swanson, J. M., & Riggs, M. (2012). The reliability and validity of the English and Spanish Strengths and Weaknesses of ADHD and Normal behavior rating scales in a preschool sample: continuum measures of hyperactivity and inattention. *J Atten Disord, 16*(6), 510-516. doi:10.1177/1087054711413550

Langley, K., Fowler, T., Ford, T., Thapar, A. K., van den Bree, M., Harold, G., . . . Thapar, A. (2010). Adolescent clinical outcomes for young people with attention-deficit hyperactivity disorder. *Br. J. Psychiatry, 196*(3), 235-240. doi:10.1192/bjp.bp.109.066274

Larsson, H., Dilshad, R., Lichtenstein, P., & Barker, E. D. (2011). Developmental trajectories of DSM-IV symptoms of attention-deficit/hyperactivity disorder: genetic effects, family risk and associated psychopathology. *J. Child Psychol. Psychiatry, 52*(9), 954-963. doi:10.1111/j.1469-7610.2011.02379.x

Lehto, J. E., Juujärvi, P., Kooistra, L., & Pulkkinen, L. (2003). Dimensions of executive functioning: Evidence from children. *British Journal of Developmental Psychology, 21*(1), 59-80. doi:10.1348/026151003321164627

Levy, F., Hay, D. A., McStephen, M., Wood, C., & Waldman, I. (1997). Attention-deficit hyperactivity disorder: a category or a continuum? Genetic analysis of a large-scale twin study. *J. Am. Acad. Child Adolesc. Psychiatry, 36*(6), 737-744. doi:10.1097/00004583-199706000-00009

Li, S., Lindenberger, U., Hommel, B., Aschersleben, G., Prinz, W., & Baltes, P. (2004). Lifespan transformations in the couplings of mental abilities and underlying cognitive processes. *Psychological science, 15*(3), 155-163.

Lubke, G. H., Hudziak, J. J., Derks, E. M., van Bijsterveldt, T. C., & Boomsma, D. I. (2009). Maternal ratings of attention problems in ADHD: evidence for the existence of a continuum. *Journal of the American Academy of Child & Adolescent Psychiatry, 48*(11), 1085-1093.

Makris, N., Biederman, J., Valera, E. M., Bush, G., Kaiser, J., Kennedy, D. N., . . . Seidman, L. J. (2007). Cortical thinning of the attention and executive function networks in adults with attention-deficit/hyperactivity disorder. *Cereb. Cortex, 17*(6), 1364-1375. doi:10.1093/cercor/bhl047

Mannuzza, S., Klein, R. G., Bessler, A., Malloy, P., & Hynes, M. E. (1997). Educational and occupational outcome of hyperactive boys grown up. *J. Am. Acad. Child Adolesc. Psychiatry, 36*(9), 1222-1227. doi:10.1097/00004583-199709000-00014

Marchetta, N. D., Hurks, P. P., Krabbendam, L., & Jolles, J. (2008). Interference control, working memory, concept shifting, and verbal fluency in adults with attention-deficit/hyperactivity disorder (ADHD). *Neuropsychology, 22*(1), 74-84. doi:10.1037/0894-4105.22.1.74

Matsuishi, T., Nagano, M., Araki, Y., Tanaka, Y., Iwasaki, M., Yamashita, Y., . . . Kakuma, T. (2008). Scale properties of the Japanese version of the Strengths and Difficulties Questionnaire (SDQ): a study of infant and school children in community samples. *Brain Dev, 30*(6), 410-415. doi:10.1016/j.braindev.2007.12.003

McGrew, K. S. (2009). CHC theory and the human cognitive abilities project: Standing on the shoulders of the giants of psychometric intelligence research. *Intelligence, 37*(1), 1-10. doi:10.1016/j.intell.2008.08.004

McLuckie, A., Landers, A. L., Rowbotham, M., Landine, J., Schwartz, M., & Ng, D. (2018). Are Parent- and Teacher-Reported Executive Function Difficulties Associated With Parenting Stress for Children Diagnosed With ADHD? *J Atten Disord*, 1087054718756196. doi:10.1177/1087054718756196

Mellor, D. (2005). Normative data for the Strengths and Difficulties Questionnaire in Australia. *Australian psychologist, 40*(3), 215-222.

Miller, M., Nevado-Montenegro, A. J., & Hinshaw, S. P. (2012). Childhood executive function continues to predict outcomes in young adult females with and without childhood-diagnosed ADHD. *J. Abnorm. Child Psychol., 40*(5), 657-668. doi:10.1007/s10802-011-9599-y

Mischel, W., Ayduk, O., Berman, M. G., Casey, B., Gotlib, I. H., Jonides, J., . . . Zayas, V. (2010). 'Willpower'over the life span: decomposing self-regulation. *Social cognitive and affective neuroscience, 6*(2), 252-256.

Mischel, W., Shoda, Y., & Rodriguez, M. I. (1989). Delay of gratification in children. *Science, 244*(4907), 933-938.

Miyake, A., & Friedman, N. P. (2012). The Nature and Organization of Individual Differences in Executive Functions: Four General Conclusions. *Curr Dir Psychol Sci, 21*(1), 8-14. doi:10.1177/0963721411429458

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: a latent variable analysis. *Cogn Psychol, 41*(1), 49-100. doi:10.1006/cogp.1999.0734

Moffitt, T. E., Arseneault, L., Belsky, D., Dickson, N., Hancox, R. J., Harrington, H., . . . Caspi, A. (2011). A gradient of childhood self-control predicts health, wealth, and public safety. *Proc. Natl. Acad. Sci. U. S. A., 108*(7), 2693-2698. doi:10.1073/pnas.1010076108

10.1073/pnas.1010076108. Epub 2011 Jan 24.

Moriguchi, Y., & Hiraki, K. (2009). Neural origin of cognitive shifting in young children. *Proc. Natl. Acad. Sci. U. S. A., 106*(14), 6017-6021. doi:10.1073/pnas.0809747106

Moriwaki, A., & Kamio, Y. (2014). Normative data and psychometric properties of the strengths and difficulties questionnaire among Japanese school-aged children. *Child and adolescent psychiatry and mental health, 8*(1), 1-1. doi:10.1186/1753-2000-8-1

Morrison, R. G., Krawczyk, D. C., Holyoak, K. J., Hummel, J. E., Chow, T. W., Miller, B. L., & Knowlton, B. J. (2004). A neurocomputational model of analogical reasoning and its breakdown in frontotemporal lobar degeneration. *J Cogn Neurosci, 16*(2), 260-271. doi:10.1162/089892904322984553

Mrug, S., Molina, B. S. G., Hoza, B., Gerdes, A. C., Hinshaw, S. P., Hechtman, L., & Arnold, L. E. (2012). Peer rejection and friendships in children with Attention-Deficit/Hyperactivity Disorder: contributions to long-term outcomes. *J. Abnorm. Child Psychol., 40*(6), 1013-1026. doi:10.1007/s10802-012-9610-2

Muris, P., Meesters, C., & van den Berg, F. (2003). The Strengths and Difficulties Questionnaire (SDQ)--further evidence for its reliability and validity in a community sample of Dutch children and adolescents. *Eur Child Adolesc Psychiatry, 12*(1), 1-8. doi:10.1007/s00787-003-0298-2

Murray, A. L., Robinson, T., & Tripp, G. (2017). Neurocognitive and Symptom Trajectories of ADHD from Childhood to Early Adolescence. *J. Dev. Behav. Pediatr., 38*(7), 465-475. doi:10.1097/DBP.0000000000000476

Nesselroade, J. R., & Baltes, P. B. (1979). History and Rationale of Longitudinal Research. In J. R. Nesselroade & P. B. Baltes (Eds.), *Longitudinal Research in the Study of Behavior and Development* (pp. 1-39). New York, NY: Academic Press.

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: views from cognitive and personality psychology and a working inhibition taxonomy. *Psychol Bull, 126*(2), 220-246.

Nigg, J. T. (2001). Is ADHD a disinhibitory disorder? *Psychol. Bull., 127*(5), 571-598. doi:10.1037/0033-2909.127.5.571

Nigg, J. T. (2009). *What Causes ADHD?: Understanding What Goes Wrong and Why*: Guilford Publications.

Nigg, J. T. (2017). Annual Research Review: On the relations among self-regulation, self-control, executive functioning, effortful control, cognitive control, impulsivity, risk-taking, and inhibition for developmental psychopathology. *J Child Psychol Psychiatry, 58*(4), 361-383. doi:10.1111/jcpp.12675

Nigg, J. T., Blaskey, L. G., Huang-Pollock, C. L., & Rappley, M. D. (2002). Neuropsychological executive functions and DSM-IV ADHD subtypes. *J Am Acad Child Adolesc Psychiatry, 41*(1), 59-66. doi:10.1097/00004583-200201000-00012

Nigg, J. T., Blaskey, L. G., Stawicki, J. A., & Sachek, J. (2004). Evaluating the endophenotype model of ADHD neuropsychological deficit: results for parents and siblings of children with ADHD combined and inattentive subtypes. *J Abnorm Psychol, 113*(4), 614-625. doi:10.1037/0021-843X.113.4.614

Nigg, J. T., Willcutt, E. G., Doyle, A. E., & Sonuga-Barke, E. J. (2005). Causal heterogeneity in attention-deficit/hyperactivity disorder: do we need neuropsychologically impaired subtypes? *Biol Psychiatry, 57*(11), 1224-1230. doi:10.1016/j.biopsych.2004.08.025

Pennington, B. F., & Ozonoff, S. (1996). Executive functions and developmental psychopathology. *J. Child Psychol. Psychiatry, 37*(1), 51-87.

Pievsky, M. A., & McGrath, R. E. (2018). The Neurocognitive Profile of Attention-Deficit/Hyperactivity Disorder: A Review of Meta-Analyses. *Arch. Clin. Neuropsychol., 33*(2), 143-157. doi:10.1093/arclin/acx055

Polderman, T. J., Derks, E. M., Hudziak, J. J., Verhulst, F. C., Posthuma, D., & Boomsma, D. I. (2007). Across the continuum of attention skills: a twin study of the SWAN ADHD rating scale. *J Child Psychol Psychiatry, 48*(11), 1080-1087. doi:10.1111/j.1469-7610.2007.01783.x

Rajendran, K., Trampush, J. W., Rindskopf, D., Marks, D. J., O'Neill, S., & Halperin, J. M. (2013). Association between variation in neuropsychological development and trajectory of ADHD severity in early childhood. *Am. J. Psychiatry, 170*(10), 1205-1211. doi:10.1176/appi.ajp.2012.12101360

Reitan, R. M. (1955). The relation of the trail making test to organic brain damage. *J. Consult. Psychol., 19*(5), 393-394.

Reitan, R. M. (1958). Validity of the Trail Making Test as an Indicator of Organic Brain Damage. *Percept. Mot. Skills, 8*(3)), 271-276. doi:10.2466/PMS.8.7.271-276

Reynolds, C. R., & Kamphaus, R. W. (1992). BASC: Behavior Assessment System for Children, Second Edition: American Guidance Services, incorporated.

Rizeq, J., Flora, D. B., & Toplak, M. E. (2017). Changing relations among cognitive abilities across development: implications for measurement and research. *Clin. Neuropsychol., 31*(8), 1353-1374. doi:10.1080/13854046.2017.1317034

Rogers, R. D., & Monsell, S. (1995). Costs of a predictible switch between simple cognitive tasks. *Journal of Experimental Psychology: General, 124*(2), 207-231. doi:10.1037/0096-3445.124.2.207

Rosch, K. S., Crocetti, D., Hirabayashi, K., Denckla, M. B., Mostofsky, S. H., & Mahone, E. M. (2018). Reduced subcortical volumes among preschool-age girls and boys with ADHD. *Psychiatry Res Neuroimaging, 271*, 67-74. doi:10.1016/j.pscychresns.2017.10.013

Rosseel, Y. (2012). lavaan: An R Package for Structural Equation Modeling. *2012, 48*(2), 36. doi:10.18637/jss.v048.i02

Rothbart, M. K., Ahadi, S. A., Hershey, K. L., & Fisher, P. (2001). Investigations of temperament at three to seven years: The Children's Behavior Questionnaire. *Child development*, *72*(5), 1394-1408.

Salthouse, T. A., Atkinson, T. M., & Berish, D. E. (2003). Executive functioning as a potential mediator of age-related cognitive decline in normal adults. *J Exp Psychol Gen*, *132*(4), 566-594. doi:10.1037/0096-3445.132.4.566

Salthouse, T. A., & Davis, H. P. (2006). Organization of cognitive abilities and neuropsychological variables across the lifespan. *Developmental Review*, *26*(1), 31-54.

Salthouse, T. A., Fristoe, N., McGuthry, K. E., & Hambrick, D. Z. (1998). Relation of task switching to speed, age, and fluid intelligence. *Psychol Aging*, *13*(3), 445-461. doi:10.1037/0882-7974.13.3.445

Sasser, T. R., Kalvin, C. B., & Bierman, K. L. (2016). Developmental trajectories of clinically significant attention-deficit/hyperactivity disorder (ADHD) symptoms from grade 3 through 12 in a high-risk sample: Predictors and outcomes. *J. Abnorm. Psychol.*, *125*(2), 207-219. doi:10.1037/abn0000112

10.1037/abn0000112.

Seidman, L. J. (2006). Neuropsychological functioning in people with ADHD across the lifespan. *Clin. Psychol. Rev.*, *26*(4), 466-485. doi:10.1016/j.cpr.2006.01.004

Shaw, P., Eckstrand, K., Sharp, W., Blumenthal, J., Lerch, J. P., Greenstein, D., . . . Rapoport, J. L. (2007). Attention-deficit/hyperactivity disorder is characterized by a delay in cortical maturation. *Proc Natl Acad Sci U S A, 104*(49), 19649-19654. doi:10.1073/pnas.0707741104

Shaw, P., Gilliam, M., Liverpool, M., Weddle, C., Malek, M., Sharp, W., . . . Giedd, J. (2011). Cortical development in typically developing children with symptoms of hyperactivity and impulsivity: support for a dimensional view of attention deficit hyperactivity disorder. *Am. J. Psychiatry, 168*(2), 143-151. doi:10.1176/appi.ajp.2010.10030385

Sibley, M. H., Pelham, W. E., Molina, B. S. G., Coxe, S., Kipp, H., Gnagy, E. M., . . . Lahey, B. B. (2014). The role of early childhood ADHD and subsequent CD in the initiation and escalation of adolescent cigarette, alcohol, and marijuana use. *J. Abnorm. Psychol., 123*(2), 362-374. doi:10.1037/a0036585

Silk, T. J., Genc, S., Anderson, V., Efron, D., Hazell, P., Nicholson, J. M., . . . Sciberras, E. (2016). Developmental brain trajectories in children with ADHD and controls: a longitudinal neuroimaging study. *BMC Psychiatry, 16*, 59. doi:10.1186/s12888-016-0770-4

Silverstein, M. J., Faraone, S. V., Leon, T. L., Biederman, J., Spencer, T. J., & Adler, L. A. (2018). The Relationship Between Executive Function Deficits and DSM-5-Defined ADHD Symptoms. *J Atten Disord*, 1087054718804347. doi:10.1177/1087054718804347

Skirbekk, V. (2004). Age and individual productivity: A literature survey: na.

Spearman, C. (1904). "General Intelligence," Objectively Determined and Measured. *The American Journal of Psychology, 15*(2), 201-292. doi:10.2307/1412107

Spector, A., & Biederman, I. (1976). Mental set and mental shift revisited. *The American Journal of Psychology, 89*(4), 669-679. doi:10.2307/1421465

Stanovich, K. E. (2009). *What intelligence tests miss: The psychology of rational thought*. New Haven, CT, US: Yale University Press.

Steinberg, L. (2005). Cognitive and affective development in adolescence. *Trends Cogn. Sci.*, *9*(2), 69-74. doi:10.1016/j.tics.2004.12.005

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*(6), 643-662. doi:10.1037/h0054651

Swanson, J. M., Kraemer, H. C., Hinshaw, S. P., Arnold, L. E., Conners, C. K., Abikoff, H. B., . . . Wu, M. (2001). Clinical relevance of the primary findings of the MTA: success rates based on severity of ADHD and ODD symptoms at the end of treatment. *J Am Acad Child Adolesc Psychiatry*, *40*(2), 168-179. doi:10.1097/00004583-200102000-00011

Swanson, J. M., Schuck, S., Porter, M. M., Carlson, C., Hartman, C. A., Sergeant, J. A., . . . Wigal, T. (2012). Categorical and Dimensional Definitions and Evaluations of Symptoms of ADHD: History of the SNAP and the SWAN Rating Scales. *Int J Educ Psychol Assess, 10*(1), 51-70.

Thorell, L. B., & Wåhlstedt, C. (2006). Executive functioning deficits in relation to symptoms of ADHD and/or ODD in preschool children. *Infant and Child Development, 15*(5), 503-518.

Todd, R. D., Huang, H., Todorov, A. A., Neuman, R. J., Reiersen, A. M., Henderson, C. A., & Reich, W. C. (2008). Predictors of stability of attention-deficit/hyperactivity disorder subtypes from childhood to young adulthood. *J. Am. Acad. Child Adolesc. Psychiatry, 47*(1), 76-85. doi:10.1097/chi.0b013e31815a6aca

Toplak, M. E., West, R. F., & Stanovich, K. E. (2013). Practitioner review: do performance-based measures and ratings of executive function assess the same construct? *J. Child Psychol. Psychiatry, 54*(2), 131-143. doi:10.1111/jcpp.12001

Toplak, M. E., West, R. F., & Stanovich, K. E. (2014). Rational thinking and cognitive sophistication: development, cognitive abilities, and thinking dispositions. *Dev. Psychol., 50*(4), 1037-1048. doi:10.1037/a0034910

Tsai, C.-J., Chen, Y.-L., Lin, H.-Y., & Gau, S. S.-F. (2017). One-year trajectory analysis for ADHD symptoms and its associated factors in community-based children and adolescents in Taiwan. *Child Adolesc. Psychiatry Ment. Health, 11*, 28. doi:10.1186/s13034-017-0165-4

Tucker-Drob, E. M. (2009). Differentiation of cognitive abilities across the life span. *Developmental psychology, 45*(4), 1097.

Tulsky, D. S., Carlozzi, N. E., Chevalier, N., Espy, K. A., Beaumont, J. L., & Mungas, D. (2013). V. NIH toolbox cognition battery (CB): measuring working memory. *Monographs of the Society for Research in Child Development, 78*(4), 70-87.

van Widenfelt, B. M., Goedhart, A. W., Treffers, P. D., & Goodman, R. (2003). Dutch version of the Strengths and Difficulties Questionnaire (SDQ). *Eur Child Adolesc Psychiatry, 12*(6), 281-289. doi:10.1007/s00787-003-0341-3

Waltz, J. A., Knowlton, B. J., Holyoak, K. J., Boone, K. B., Mishkin, F. S., de Menezes Santos, M., . . . Miller, B. L. (1999). A system for relational reasoning in human prefrontal cortex. *Psychological science, 10*(2), 119-125.

Wechsler, D. (1999). *Wechsler Abbreviated Scale of Intelligence WASI: Manual*: Pearson/PsychCorpl.

Willcutt, E. G., Doyle, A. E., Nigg, J. T., Faraone, S. V., & Pennington, B. F. (2005). Validity of the executive function theory of attention-deficit/hyperactivity disorder: a meta-analytic review. *Biol. Psychiatry, 57*(11), 1336-1346. doi:10.1016/j.biopsych.2005.02.006

Woerner, W., Becker, A., & Rothenberger, A. (2004). Normative data and scale properties of the German parent SDQ. *European Child & Adolescent Psychiatry, 13*(2), ii3-ii10. doi:10.1007/s00787-004-2002-6

Young, D. J., Levy, F., Martin, N. C., & Hay, D. A. (2009). Attention deficit hyperactivity disorder: a Rasch analysis of the SWAN Rating Scale. *Child Psychiatry and Human Development, 40*(4), 543-559.

Zelazo, P. D., Anderson, J. E., Richler, J., Wallner-Allen, K., Beaumont, J. L., & Weintraub, S. (2013). II. NIH Toolbox Cognition Battery (CB): measuring executive function and attention. *Monogr Soc Res Child Dev, 78*(4), 16-33. doi:10.1111/mono.12032

Zelazo, P. D., Craik, F. I., & Booth, L. (2004). Executive function across the life span. *Acta Psychol (Amst), 115*(2-3), 167-183. doi:10.1016/j.actpsy.2003.12.005

Zelazo, P. D., Muller, U., Frye, D., Marcovitch, S., Argitis, G., Boseovski, J., . . . Sutherland, A. (2003). The development of executive function in early childhood. *Monogr Soc Res Child Dev, 68*(3), vii-137.

Appendix

Data Analysis: Growth Curve Trajectory Models of SWAN data

All models were estimated using full-information maximum-likelihood; this procedure allows data from participants with incomplete data (including longitudinal dropouts) to be incorporated in the model estimation (see (Bollen & Curran, 2006), which is essential given that we organized the data according to the age categories described above. All models were estimated using Mplus (version 7.3). For the SEMs, overall model fit was assessed using the indices described earlier.

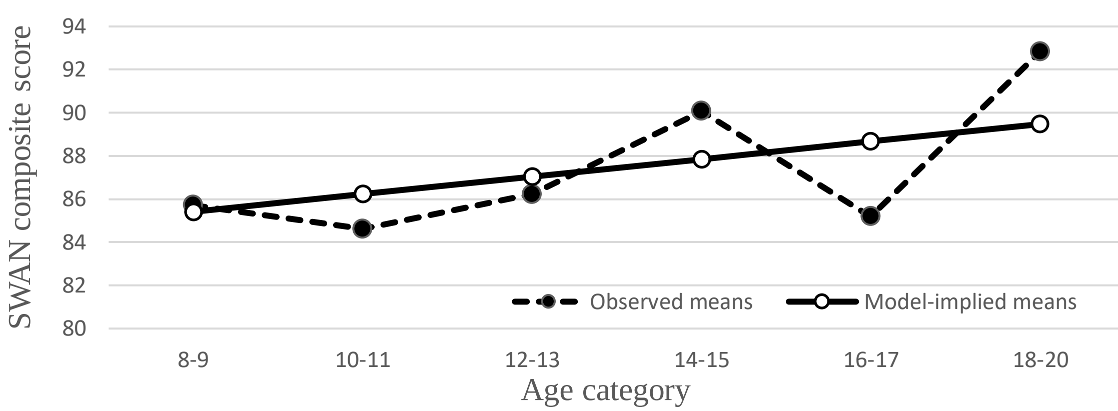
Because there was considerable age heterogeneity within each time point, we modeled developmental trajectories of cognitive abilities and parent-reported attention and impulsivity as a function of age rather than time point of data collection (i.e., the data are consistent with a cohort-sequential design; (Nesselroade & Baltes, 1979). Specifically, because participant ages ranged from 8 years to 20 years across T1 to T3, a long-term developmental trajectory could be approximated by combining the temporally overlapping repeated measures of youth observed at different ages. Thus, with only three time points of data collection, the age-based data were linked to form a common developmental trajectory spanning ages 8 to 20, albeit with substantial amounts of missing data within a given year of age. In fact, the sparseness of data at some ages necessitated collapsing age into the following six categories to facilitate convergence of model estimation: age 8-9 (age category 1; n = 90 observations; 49 males, 41 females), 10-11 (age category 2; n = 89 observations; 55 males; 34 females), 12-13 (age category 3; n = 112 observations; 57 males, 55 females), 14-15 (age category 4; n = 107 observations; 59 males; 48 females), 16-17 (age category 5; n = 60 observations; 36 males, 24 females), and 18-20 (age category 6; n = 28 observations; 13 males, 15 females).

Results: Developmental Trajectories

Parent-reported attention/ impulse regulation. The mean score of the SWAN composite variable from the SWAN displayed a linear trend across the six age categories, such that the means increased from age 8-9 up to age 18-20. Impulsivity, Hyperactivity and Inattention subscales exhibited a similar trend. As such, linear growth curve models were fitted to the data.

The linear growth curve model for SWAN composite score is shown in Figure 3. The mean slope was significantly greater than 0 (0.81, p = .04), while the variance of the slope factor was not significant (4.29, p = .45). These results suggest that, consistent with the existing literature, parent-reported attention/impulse regulation general improve as children get older. However, there are not substantial individual differences in the amount that SWAN composite score scores change across age. Given the lack of variance in slope, it is not possible to examine whether factors such as cognitive abilities play a role in affecting the rate of change.

Figure 3.
Developmental trajectory of SWAN composite score

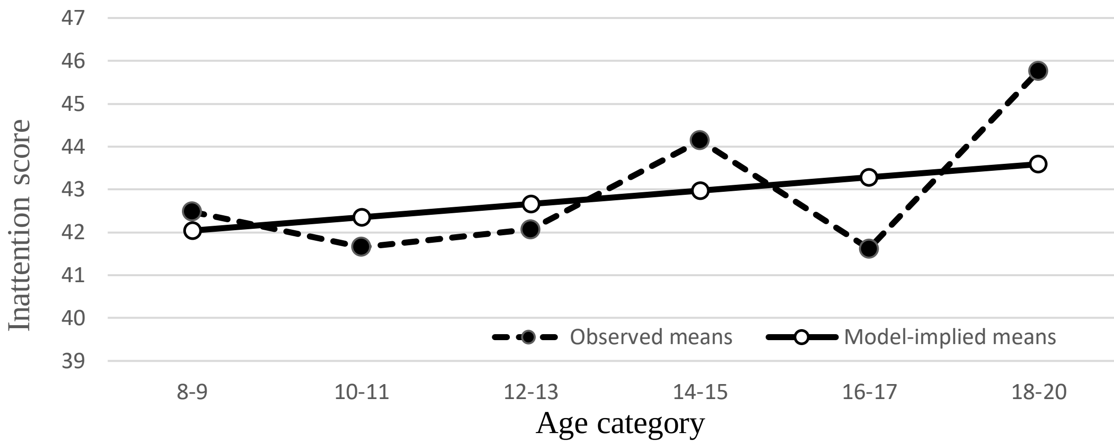


Linear growth curve models of SWAN subscales are presented in Figure 4. The mean slopes were significantly greater than 0 for both impulsivity (0.16, SE = 0.08, p = .05) and hyperactivity (0.35, SE = .15, p = .02) subscales, but not inattention (0.31, SE = 0.23, p = .17). Like the SWAN composite, the variance of the slope factor is not significant for impulsivity

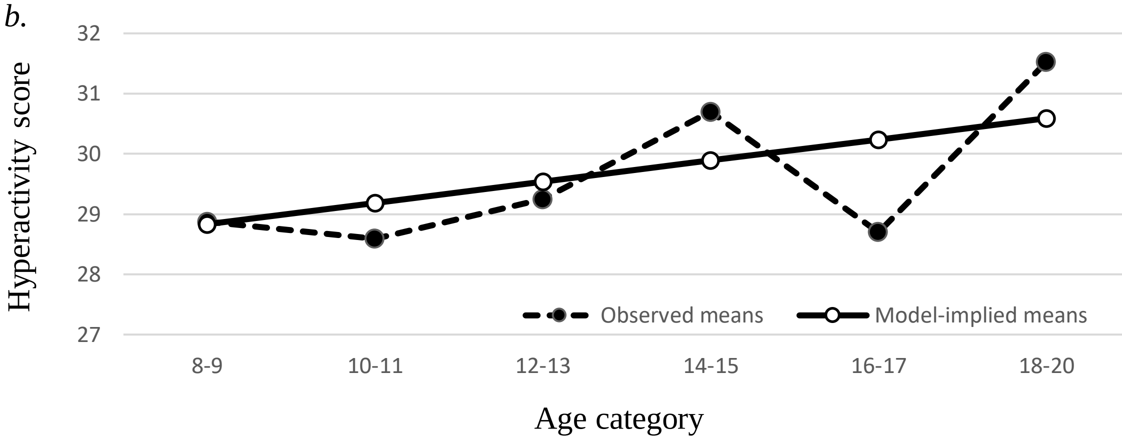
(0.28, *SE* = .19, *p* = .14), hyperactivity (0.03, *SE* = 0.75, *p* = 0.96) or inattention (1.66, *SE* = 1.89, *p* = 0.38) subscales. Consistent with our current understanding of the trajectory of ADHD symptoms in children with ADHD, in this sample impulsivity and hyperactivity improved with age, whereas inattention did not change in meaningful way. Like the SWAN composite, the model suggests that there is essentially no intra-individual heterogeneity in the amount that each of the subscale scores change across age.

Figure 4.
Developmental trajectories of SWAN subscale scores

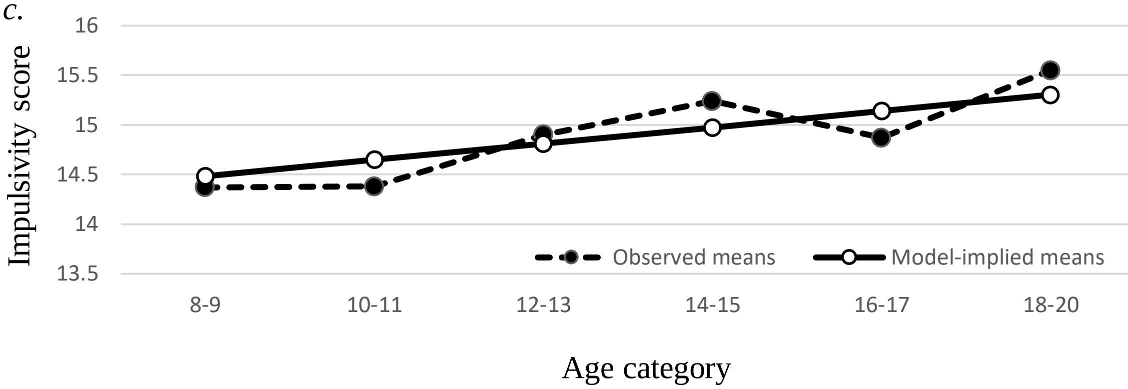
a.



b.



c.


16
15.5
15
14.5
14
13.5
Impulsivity score
Observed means
Model-implied means
8-9
10-11
12-13
14-15
16-17
18-20
Age category